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COST OF CLEAN WATER. VOLUME II. COST EFFECTIVENESS AND CLEAN WATER

Environmental Protection Agency
Washington, D. C.

March 1971

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COST OF CLEAN WATER

VOLUME 11

COST EFFECTIVENESS
AND
CLEAN WATER

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ENVIORNMENTAL PROTECTION AGENCY
WATER QUALITY OFFICE
MARCH 1971

ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF THE ADMINISTRATOR

Honorable Spiro T. Agnew
President of the Senate
Washington, D. C. 20510

Dear Mr. President:

I am transmitting to the Congress the fourth annual report on the national requirements and costs of water pollution control as required under Section 26(a) of the Federal Water Pollution Control Act, as amended.

Our current estimate of investment requirements for municipal treatment works is $12 billion as reflected in the legislative proposal transmitted last month.

Volume I of the report, Municipal Investment Needs, describes the analyses and surveys which were undertaken in arriving at this estimate of investment needs. The results of these studies led to a request for a $6 billion Federal program, $2 billion in each of the Fiscal Years 1972-1974 to meet total investment goals of $12 billion.

The several analyses of investment requirements made over time, by contacts with communities, construction grant project reporting systems and statistical models, showed a substantial variability in the investment needs as reported over time by individual States and municipalities. The reasons for variability include changes in treatment requirements imposed by water quality standards, impacts of inflation in the construction sector, construction schedule changes, refinement of individual plant cost estimates as construction nears, and community expectations with respect to magnitude and direction of Federal and State assistance programs.

The size, complexity and dynamic nature of the municipal investment in waste treatment systems prevent the development of fixed long term estimates and point instead toward a need for periodic reappraisal. It is also abundantly clear that reappraisals must make adequate provisions for incorporating new solutions to waste problems rather than continuing commitment to out-dated plans or technologies.

Our analyses this year, as in previous years, have addressed the issues of cost-effectiveness, industrial utilization of municipal facilities and sewerage service charges. There is no doubt that a massive investment program is needed, but the absolute magnitude of the investment required to produce a given set of waste reduction effects will vary depending upon the allocation of resources to projects and the degree of cost-effectiveness with which investments are made.

Volume II, Cost-Effectiveness and Clean Water addresses several of the issues associated with planning, design and operating inefficiencies. While construction sector inflation and changing requirements will operate to increase costs, there is convincing evidence that substantial savings in investment requirements can result from cost-effective planning of municipal waste systems. This has been clearly demonstrated through our experience in reviewing community waste treatment proposals. We are working to influence such decisions through our administration of the Federal grant program.

The results of user charge and cost analyses lead us to believe that a high order of municipal utility management coupled with an adequate user charge system could lead to self-sufficient utility based municipal systems freeing them from dependence on Federally dominated categorical grant programs. In addition, such user charge systems should encourage industries to reduce their wastes.

Our recent legislative proposal, the regulations promulgated on July 2, 1970, directed toward planning requirements, and new planning guidelines published on January 29, 1971, direct themselves to the significant questions of self-sufficiency and cost-effectiveness. Further intensive efforts in this important area are underway in the Environmental Protection Agency.

The Administration has taken action to control the impact of sectoral inflation in the construction industry. As pointed out in the current report, past construction sector inflation has served to raise investment needs. These actions, coupled with cost-effective investment planning, can be expected to increase productivity of the waste facilities dollar.

In the broader scope of water quality management, we must not ignore the problems posed by waste sources other than municipal sources and which are in many cases infinitely more complex to solve. Volume II therefore includes an initial assessment of the relative cost-effectiveness of investments in terms of these several problem areas. These analyses provide a point of departure for developing and implementing cost-effective abatement of water pollution across its many sources. This approach is part of the Environmental Protection Agency's effort to develop more effective integrated approaches to environmental management.

Sincerely yours,

William D. Ruckelshaus
Administrator

Enclosure

V

ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D. C. 20460

OFFICE OF THE
ADMINISTRATOR

Honorable Carl B. Albert
Speaker of the House of
Representatives
Washington, D. C. 20515

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William D Ruckelshaus

William D. Ruckelshaus
Administrator

Enclosure

VOLUME II

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COST EFFECTIVENESS AND CLEAN WATER

INTRODUCTION

The report

~~This~~ is the fourth in a series of reports to the Congress, that have been prepared in compliance with Section 26(a) of the Federal Water Pollution Control Act, as amended, that directs that the Administrator of the Environmental Protection Administration "make. . .a comprehensive analysis of the national requirements for and the cost of treating municipal, industrial, and other effluents to attain. . .water quality standards. . .established pursuant to this Act or applicable State law."

Previous studies have examined the total amount and the distribution of waste treatment requirements for public agencies and for industry, and have considered, to the extent that information and programs were developed, the kinds and costs of controls that might be directed at non-sewered pollutants.

The data which have been presented and analyzed in the previous reports have been addressed to normative rates of investment on a national basis, although last year's report began to investigate regional differences in costs. Data available then as well as new data provided the Agency by States in the past year show wide disparities in unit prices. Indicated per capita investment requirements reported by the States for municipal waste treatment over the next five years range from almost $500 to less than $10.

Over the last decade, the nation has almost doubled its waste treatment capitalization and will double it again in the next five years. Yet the public hears little of accomplishment, and, quite the contrary is often led to believe that little has been done to control sewered wastes.

An immutable tendency seems to be that as Federal financial assistance and investment increases, physical plant expands; and as physical plant expands, the volume of capital needs involving Federal financial assistance also expands. The more we invest, the more we seem to need to invest. The reasons for and effects of factors causing this are discussed in Volume I.

But it is also possible that much of the capital need flows from institutional inefficiencies at all levels of government, that some of the increase in costs of pollution abatement could be controlled by more efficient utilization of capital, and that more rapid progress in pollution abatement could be achieved by alternative investment arrangements.

This volume of the report, then, considers the question of efficiency, directing its attention to: 1) the distribution of investments as compared to the distribution of polluting activities and the location of water pollution: 2) the results of municipal and industrial waste treatment investments made over the life of the Federal construction grant program, in terms of reduction of oxygen demand and nutrients in sewage; 3) avoidable increase in local operating, maintenance, financing, and overhead costs of waste treatment; and 4) the questionable strategy of making use of investment capital essentially to forestall some future needs, and at the same time permitting the persistence of existing treatment system deficiencies.

INVESTMENT IN 1970 AND THE NATIONAL GOAL

A significant change in the conduct of water pollution control programs took place in 1970, when the Federal Government established a distinct objective for programs in support of public waste treatment. The program was intended to "provide every community that needs it with secondary waste treatment, and also special additional treatment in areas of special need. . .". From this objective, to be met in a five-year period, can be inferred the attainment of a condition in which required investments for waste treatment and related purposes (i.e., projects entitled to Federal assistance under Public Law 84-660) would be no greater in any year than the amount of the requirements generated in that year. On the basis of exhaustive analysis involving two parallel studies that employed widely different methods--macroeconomic projection of the interaction of demand constituents on the one hand, inventorying of locally determined construction requirements on the other--it was determined that no less than $2 billion a year of investment must be elicited over the five years 1970 to 1974 if the goal were to be attained. Descriptions of these analyses were transmitted to the Congress in the March, 1970 report, The Economics of Clean Water. That report emphasized that the amount of necessary expenditure was not fixed, but rather was a consequence of a series of functions, including price level changes, technological mixes, resource availability, and--most significant of all--the annual rate of investment.

As indicated in Volume I, during the course of the year 1970 it became obvious that several conditions were acting to upset the resolution of the proposed $10 billion investment program. These include more stringent treatment requirements, improved perception of needs, refinements of estimates and construction sector inflation.

At the same time and in spite of the availability of expanded Federal and State financial assistance, investment in 1970 did not achieve the $2 billion annual level thought to be required to sustain progress toward the provisional five year goal of complete availability of waste treatment services compatible with water quality standards. By the end of 1970, over $3 billion of Federally assisted works were under construction, and about $1.2 billion worth of Federally assisted projects were begun during the year--up from $365 million in 1969. But neither value could be considered sufficient to sustain progress toward the targeted goal. Table I shows a comparison of actual events in 1970 with those of 1969.

TABLE I

The Investment Picture 1969 and 1970
(Million Dollars)

	1969	1970
Works under Construction	2224	3398
New Starts	937	1174
Completions	375	187

Most of the States seem to be recognizing the impact of these events on their own circumstances. Each State was requested during June 1970 to estimate on a point by point basis the desirable level of capitalization of waste treatment works for the four fiscal years 1971 through 1974 as described in Volume I.

Faced with a similar request in 1969, the States had estimated a total need for $10.2 billion of investment capital over five years. In June 1970, they expressed a collective need for $12.2 billion--but in four years. (cf. Table 3). A more recent survey taken as of December 1970 shows a total need of $12.6 billion. The December estimates are shown in Table 3.

A careful State-by-State review of the data summarized in Tables 2 and 3 suggests that there may be a significant amount of uncertainty involved in local estimates of needs. In the course of a single year, ten States' estimates of need increased by 100% or more, in spite of investment occurring in the year. Granted that the scheduling of particular large projects will have a significant effect on the distribution of requirements in any period, it seems unlikely that one State in five would suddenly feel the need to initiate projects of such significant magnitude in a single year. Rather, it would appear that there were either real changes in conditions, or that much of what was required in 1969 was simply overlooked in that year.

On the brighter side, sixteen States provided capital estimates that suggest that they have reduced their backlog of needed works during 1970. Fewer dollars will be required, if their estimates are good, to improve and maintain their public waste handling systems in the four years 1971 to 1974 than in the five years 1970 to 1974. In addition, nine States held their own, in the sense that their projected levels

TABLE 2
INDIVIDUAL STATES' ASSESSMENTS OF CAPITAL REQUIREMENTS,
1969 and 1970

	Indicated FY 1971-4 Needs		Indicated FY 1970-4 Needs		Net Change		% Change in Annual Per-Capita
Location	$Millions	$Per-Capita*	$Millions	$Per-Capita*	$Millions	$Per-Capita*	Needs
California	922.79	47.81	651.8	33.77	+271.0	+14.04	77%
Idaho	11.44	16.27	0.5	0.71	+ 10.9	+15.56	2764%
Nevada	57.86	128.87	28.6	63.97	+ 29.3	+65.17	152%
Oregon	104.65	52.12	135.0	67.23	- 30.4	-15.11	-3%
Washington	214.74	65.55	160.0	48.84	+ 54.7	+16.71	50%
Pacific Coast	1311.48	50.96	975.9	37.92	+335.5	+13.04	68%
Iowa	66.77	24.07	33.3	12.00	+ 33.5	+12.07	151%
Minnesota	161.67	44.33	136.3	37.37	+ 25.4	+ 6.96	48%
Missouri	327.10	70.72	390.0	84.32	- 62.9	-13.60	5%
Montana	15.67	22.62	13.5	19.48	+ 2.2	+ 3.17	45%
Nebraska	74.70	51.91	62.0	43.09	+ 12.7	+ 8.83	51%
North Dakota	7.55	12.04	22.0	35.09	- 14.5	-23.05	-57%
South Dakota	17.25	26.30	27.0	41.16	- 9.8	-14.86	-20%
Wyoming	1.80	5.71	12.0	38.10	- 10.2	-32.38	-81%
Northern Plains	672.51	45.51	696.1	47.11	- 23.6	- 1.60	21%
Arizona	78.75	47.36	86.0	51.71	- 7.3	- 4.36	14%
Arkansas	30.50	15.36	33.0	16.62	- 2.5	- 1.26	16%
Colorado	45.10	22.08	133.0	65.10	- 87.9	-43.03	-58%
Kansas	61.80	26.95	61.0	26.60	+ 0.8	+ .35	27%
New Mexico	10.60	10.54	9.9	9.84	+ 0.7	+ .70	34%
Oklahoma	78.80	31.27	65.3	25.91	+ 13.5	+ 5.36	51%
Texas	573.70	52.26	525.0	47.83	+ 48.7	+ 4.44	37%
Utah	33.67	32.56	11.7	11.32	+ 22.0	+21.25	260%
Southern Plains	912.92	38.81	924.9	39.32	- 12.0	- .51	23%
Alabama	45.45	12.77	35.0	9.39	+ 10.5	+ 2.94	70%
Florida	457.10	74.31	200.0	32.52	+257.1	+41.80	186%
Georgia	177.62	38.88	150.0	32.84	+ 27.6	+ 6.05	48%
Kentucky	94.59	29.38	62.6	19.44	+ 32.0	+ 9.93	89%
Louisiana	162.00	43.48	140.0	37.57	+ 22.0	+ 5.90	45%
Mississippi	42.96	18.33	40.0	17.06	+ 3.0	+ 1.26	34%
North Carolina	122.02	23.82	69.3	13.53	+ 52.7	+10.29	120%
South Carolina	58.29	21.88	75.0	28.15	- 16.7	- 6.27	-3%
Tennessee	138.08	34.74	105.5	26.54	+ 32.6	+ 8.20	64%
Virginia	220.70	48.03	151.0	32.86	+ 69.7	+15.17	83%
Southeast	1518.81	38.04	1028.4	28.61	+490.5	+13.64	66%
Delaware	63.20	118.35	28.0	52.43	+ 35.2	+65.92	182%
District of Columbia	380.50	470.33	355.0	438.81	+ 25.5	+31.52	34%
Illinois	695.27	63.26	437.2	39.78	+258.1	+23.48	99%
Indiana	151.17	29.87	152.6	30.15	- 1.4	-.28	24%
Maryland	247.68	65.98	236.9	63.11	+ 10.8	+ 2.87	31%
Michigan	690.69	79.04	253.7	29.03	+437.0	+50.00	240%
Ohio	442.32	41.78	432.5	40.85	+ 9.8	+ .93	28%
West Virginia	49.87	27.67	44.3	24.58	+ 5.6	+ 3.09	41%
Wisconsin	139.88	33.14	243.7	57.74	-103.8	-24.60	-28%
Central	2860.58	61.52	2183.9	46.97	676.8	14.55	64%
Connecticut	231.60	78.16	280.5	94.67	- 48.9	-16.50	3%
Maine	137.90	141.29	140.9	144.36	- 3.0	- 3.07	22%
Massachusetts	470.40	86.01	438.0	80.09	+ 32.4	+ 5.92	34%
New Hampshire	163.15	232.41	138.0	196.58	+ 25.2	+35.83	48%
New Jersey	1187.60	167.43	880.0	124.07	+307.6	+43.37	69%
New York	1859.80	102.88	1900.1	105.11	- 40.3	- 2.23	22%
Pennsylvania	567.07	48.35	432.0	36.83	+135.1	+11.52	64%
Rhode Island	43.30	47.37	51.5	56.35	- 8.2	- 8.97	5%
Vermont	41.20	96.94	70.0	164.71	- 28.8	-67.76	-26%
Northeast	4702.02	97.25	4331.0	89.58	+371.1	+ 7.68	36%
Alaska	35.89	130.97	12.0	43.80	+ 23.9	+87.19	274%
Guam	14.23	18.97	6.2	8.27	+ 8.0	+10.71	187%
Hawaii	82.55	105.84	14.4	18.46	+ 68.2	+87.37	617%
Puerto Rico	61.95	22.75	28.9	10.61	+ 33.1	+12.14	168%
Virgin Islands	16.56	44.76	15.4	41.62	+ 1.2	+ 3.14	34%
Non-Contiguous	211.18	43.12	76.9	18.68	+134.4	+32.65	189%
U.S. TOTAL	12189.48	60.62	10217.1	50.81	+1972.4	+ 9.81	49%

* U. S. Bureau of Census Estimate of 1968 Population

TABLE 3

Fluctuations in State Estimates of Capital Needs
June 1970 and December 1970
(Million Dollars)

Location	Indicated FY 1971-4 Needs June 1970	 December 1970	% Change
Needs Increase ≥75%			
Montana	15.67	31.4	100.4
New Mexico	10.60	19.6	84.9
Minnesota	161.67	295.2	82.6
Needs Increase 50-74.9%			
Iowa	66.77	111.9	67.6
Ohio	442.32	733.5	65.8
Illinois	695.27	1043.6	50.1
Puerto Rico	61.95	93.0	50.1
Needs Increase 25-49.9%			
Maryland	247.68	349.7	41.2
Arkansas	30.50	42.0	37.7
Wisconsin	139.88	190.8	36.4
Virginia	220.70	280.1	26.9
Idaho	11.44	14.5	26.7
Needs Increase 10-24.9%			
Kentucky	94.59	117.0	23.7
Indiana	151.17	174.8	15.6
Michigan	690.69	788.8	14.2
Maine	137.90	157.4	14.1
North Dakota	7.55	8.4	11.3
New Jersey	1187.60	1309.7	10.2
Needs Increase 5.1-9.9%			
Pennsylvania	567.07	616.4	8.7
Colorado	45.10	47.4	5.1
Needs Change ±5%			
West Virginia	49.87	51.4	3.1
North Carolina	122.02	125.3	2.7
Washington	214.74	216.3	0.7
Connecticut	231.60	229.5	-0.9
South Carolina	58.29	57.6	-1.2
Delaware	63.20	62.0	-1.9
Florida	457.10	444.2	-2.8
Needs Decrease 5.1-10%			
Wyoming	1.80	1.7	-5.6
New York	1859.80	1721.0	-7.5
Vermont	41.20	38.0	-7.8
District of Columbia	380.50	347.2	-8.8
Needs Decrease 10.1-25%			
Massachusetts	470.40	422.6	-10.2
Oklahoma	78.80	69.8	-11.4
Virgin Islands	16.56	14.6	-11.8
Rhode Island	43.30	37.7	-12.9
Kansas	61.80	52.7	-14.7
New Hampshire	163.15	137.8	-15.5
Missouri	327.10	268.2	-18.0
Louisiana	162.00	132.7	-18.1
Nevada	57.86	47.2	-18.4
California	922.79	737.5	-20.1
Mississippi	42.96	34.1	-20.6
Alaska	35.89	28.1	-21.7
South Dakota	17.25	13.5	-21.8
Oregon	104.65	78.6	-24.9
Needs Decrease > 25.1%			
Texas	573.70	398.7	-30.5
Guam	14.23	9.7	-31.8
Utah	33.67	22.6	-32.9
Nebraska	74.70	49.0	-34.4
Arizona	78.75	51.0	-35.2
Tennessee	138.08	88.9	-35.6
Hawaii	82.55	50.8	-38.5
Alabama	45.45	27.0	-40.6
Georgia	177.62	74.0	-58.3
U. S. TOTALS	12,189.48	12,565.2	3.1

of expenditures did not increase more than indicated by the impact of 1970 inflation--9.8%, given the normal mix of transmission and treatment plant investment. Twenty-five of the fifty-four States (i.e., fifty States, plus the District of Columbia, Guam, Puerto Rico, and the Virgin Islands) reduced or maintained the backlog of needed works, while twenty-nine indicated that backlogs increased during 1970.

Due to the changeable nature of the State-by-State estimates made in 1969 and 1970 it seems reasonable to conclude that the $12.6 billion estimate in Table 3 does not represent a fixed estimate of investment need. As discussed in following chapters, it appears that cost effective opportunities exist which, if carefully implemented, could result in substantial overall savings for the nation. These chapters describe various practices and policies which affect cost. It is also clear from these estimates, showing a $2.4 billion increase over the 1969 estimate, that annual investment will have to be accelerated above the $2 billion level deemed necessary in last years report.

As in previous years, estimates of industrial capital expenditures were available only from sources outside of government. Perhaps the best of these is the McGraw-Hill survey, conducted annually as a portion of that service's quarterly capital spending survey. The report's results--which do not distinguish between air and water pollution control investments--are contained in Table 4.

There are some interesting features hidden in the data. First, actual investments reported for 1968 are somewhat above the investments previously reported for that year. Presumably, the deviation results from the process of extrapolating from a differently constituted sample. Though not a significant difference (7.2% for the manufacturing sector), the fact of difference indicates some of the difficulities involved in dealing with these very slippery data. Second, actual investments reported for 1969 are 15% higher than planned for that year--almost an exact reversal of the previous year, when outlays did not meet initial intentions. Perhaps the easing of the capital spending boom eliminated delivery and construction bottlenecks--or perhaps the differences are attributable to sampling variability.

While the McGraw-Hill survey provides no information with respect to the distribution of expenditures for air pollution control vs. water pollution control, another source, the National Industrial Conference Board, does make that distinction. Unfortunately, the NICB's most recent survey was for the year 1968, and so is of less immediate interest than the McGraw-Hill report. It may be considered significant, however, that the NICB data corroborate a steady upward trend in total industrial investment for environmental pollution control. They also

Table 4

INDUSTRIAL INVESTMENT IN AIR AND WATER POLLUTION CONTROL McGRAW-HILL SURVEY

	*Normalized Water Component	Millions of Dollars			
		1967	1968	1969	1970(Planned)
Iron & Steel	48%	130	119	179	199
Non-ferrous metal	NA	43	15	41	84
Machinery	60%	46	113	83	149
Transportation Eqt.	20&	76	54	92	120
Stone, Clay & Glass	40%	48	40	63	95
Other Durables	NA	45	68	172	163
Chemical	48%	92	109	140	226
Pulp & Paper	65%	94	82	143	184
Rubber	50%		10	9	20
Petroleum	48%	102	170	260	205
Textiles	75%	7	9	10	23
Food & Pdts.	55%	42	23	58	91
Other nondurables	NA	53	20	31	57
Manufacturing Total	50%	785	832	1281	1614
Electric & Gas Utilities	NA	215	244	285	544
Mining	NA	66	56	105	126

*Based on series of NICB Surveys and not a part of the McGraw-Hill Report suggest that a steadily decreasing share of that investment goes into water pollution abatement facilities. From 55% in 1962, water's share dropped to 50% of manufacturing outlays in 1968; and some of the larger and more significant industrial components--primary metals, petroleum, and chemicals--now would seem to devote less than half of their pollution control investment to water pollution purposes. Whether the phenomenon is due to a more stringently enforced set of air pollution regulations or to a more fully available set of wastewater treatment controls, it is impossible to say, given our limited existing knowledge of industrial waste treatment facilities and investment.

It is expected that the recently initiated National Industrial Waste Inventory will improve our base of knowledge in the industrial sector. The next report in this clean water series should be able to provide an assessment of the progress made toward control of industrial wastes. In addition to the data which will become available through the inventory, the study being conducted for the Environmental Protection Agency, Water Quality Office by the National Industrial Conference Board will provide investment information on industrial waste treatment facilities in place and planned for the future. This report should be completed during the middle of calendar year 1971.

THE CAPITALIZATION OF WASTE TREATMENT FACILITIES

Situation

Aggregate daily waste production and discharge, in terms of five day biochemical oxygen demand (BOD$_5$), are estimated to have a configuration approximately like that shown in Table 5. Mean waste production is estimated to be over 120 million pounds per day, and mean discharge 45 to 50 million pounds per day, thirty percent reaching water through the outfalls of public systems in standard metropolitan statistical areas, five percent occurring through the discharges of communities outside SMSA's, sixty-five percent occurring through separately discharging factories. Over-all effectiveness of waste treatment is estimated to amount to greater than sixty percent reduction of BOD, or very close to seventy percent of theoretical limits for conventional waste treatment; and reduction of oxygen demand of sanitary sewage approaches 65%. (cf. Table 6.)

Those relationships represent a substantial, though generally unrecognized, accomplishment of the American economy. Consider the situation. When World War II ended, less than 75 million Americans were provided with sewer services, compared to 140 million today. And of those 75 million, roughly 30 million--or forty percent--were discharging raw wastes. Industrial waste treatment simply did not exist in 1945, except as provided by light industry attached to sewers in communities that happened to supply waste treatment. While we have no information on either the distribution of waste treatment techniques or the volume of industrial waste, it is not unreasonable to assume that no more than half of municipal waste treatment capacity represented secondary treatment,and the professional judgement of the period included the assessment that industrial wastes were as great in volume as domestic (probably a considerable underestimate, in the light of later knowledge). Using such crude estimates, the aggregate level of BOD reduction could have been little more than 16% to 33% of domestic waste strength, and nothing for an equal volume of industrial wastes.

Between 1945 and 1968, then, the economy increased the relative effectiveness of its waste treatment fourfold, in the face of an expansion of waste production that may have amounted to as much as 390% of the 1945 level. Certainly that investment program must stand beside highway construction and physical expansion of educational facilities as an accomplishment, though the latter phenomena have received a great deal of attention, while the expansion of waste treatment has gone almost unnoticed. (Here, however, the discussion relates only to the significant magnitude of construction works. As shall be discussed later, this same significance does not carry over to change in pollutants discharged to the nation's waters.)

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TABLE 5
COMPONENTS OF NATIONAL SEWERED
WASTE DISCHARGE, 1968

Waste Source	Million pounds BOD_5 / DAY				
	Produced	Percent of Total Produced	Discharged	Percent of Total Discharged	Percent Reduced by Treatment
Metropolitan population	17.9	14.7	6.4	13.9	64.3
Non-metropolitan population	5.3	4.3	1.8	3.9	66.0
Separately discharging industries*	80.0	65.5	30.7	66.6	61.6
Industries discharging through metropolitan plants	18.2	14.9	7.2	15.6	60.7
Industries discharging through non-metropolitan plants	0.7	0.6	0.4	0.9	42.9
TOTAL	122.1	100.0	46.1	100.0	62.2
(Industrial Total)	98.9	81.0	38.3	83.1	61.3
(Population Total)	23.2	19.0	8.2	1.8	64.6
(Through metropolitan plants)	36.1	29.6	13.6	29.5	62.3
(Through non-metropolitan plants)	6.0	4.9	2.2	4.8	63.3

*Assumes 300 day average operating year

TABLE 6
DISTRIBUTION OF MUNICIPAL WASTE TREATMENT TECHNIQUES, 1962 and 1968

Technique	Mean BOD Removal	1962 Plants	1962 1000's Served	1962 Indicated* Removal	1968 Plants	1968 1000's Served	1968 Indicated* Removal
Imhoff or Septic Tanks	30%	1,592	3,173.7	952.1	1,179	2,864.4	859.3
Primary Treatment	37%	1,088	30,052.0	11,119.2	1,212	34.112.6	12,621.7
Chemical Treatment	60%	84	7,408.5	4,445.1	75	5,857.7	3,514.6
Lagoons	83%	1,402	2,265.4	1,880.3	3,471	6,142.9	5,098.6
Biological Filters	81%	3,540	23,282.4	18,858.7	3,813	29,618.2	23,990.7
Activated Sludge	87%	798	33,276.3	28,950.4	1,312	38,560.9	33.548.0
Extended Aeration	88%	155	406.2	357.5	801	2,704.7	2,380.1
Other Secondary	85%	.132	529.9	450.4	197	7,886.4	6,703.4
Land Disposal	99%	266	1,220.0	1,207.8	128	412.7	408.6
Int. Sand Filters	95%	342	505.2	479.9	247	331.9	315.3
Tertiary Treatment	94%	0	0	0	10	325.5	306.0
Total Treatment Systems	1962 - 67.3% 1968 - 64.6%	9,399	102,119.6	68,701.4	12,445	128,817.8	89,746.4
Untreated Discharge	0%	2,068	16,233.9	0	1,402	10,176.0	0
Total Sewer Systems	1962 - 58.1% 1968 - 64.6%	11,467	118,353.9	68,701.4	13,847	138,993.8	89,746.4

*Population served X mean removal = indicated gross removal of BOD, in population equivalents (6 P.E. = 1 lb. of BOD_5) and for domestic wastes only

Much of the expansion of waste treatment services has taken place fairly recently. Between 1945 and 1949 incremental waste treatment service reached only 2 million persons, and public works activities of all types were slow paced during the Korean War. But from 1952 to the present, outlays for construction of waste treatment plants and related works have increased in almost every year. (cf. The Cost of Clean Water and Its Economic Impact, U.S.D.I., January 1969, Tables 4,5). In sum, that investment is estimated to have exceeded $16 billion at this writing.

The general dimensions of the investment, through 1968, are summarized by source in Table 7. Some of the obvious aspects of the current investment picture come into clear relief when arrayed in this form:

1) The major burden of investment has been borne by public agencies, and particularly by those located in standard metropolitan statistical areas where almost 70% of U. S. population is concentrated.

2) A significant portion of the higher investment by the public sector may be ascribed to the necessity of transmitting wastes to and from treatment plants. The network of interceptor sewers, pumping stations, and outfalls required in connection with the waste treatment process accounts for 70% of investment in metropolitan areas, and almost 25% in non-metropolitan urban areas and in rural communities.

3) Unit investments vary sharply between metropolitan, non-metropolitan, and industrial waste sources. The pattern follows closely the relative volume of wastes from the three sources, in that the more signficiant the waste-producing category, the less must be invested to achieve a given degree of treatment effectiveness, since--as Table 5 indicates--the aggregate degree of treatment is estimated to be approximately the same for metropolitan areas, non-metropolitan areas, and for industry. Those relationships are largely determined by some basic condition sets that have been examined at length in earlier reports in this series. (See The Economics of Clean Water, U.S.D.I., FWQA March 1970.)

a) The relative efficiency, in terms of unit cost of removal, displayed by metropolitan area and industrial waste treatment systems arises in part from the obvious economies of scale available to them. Concentrated wasteloads, either expressed as number of people available within the reach of a given treatment plant, or in terms of the volume of wastes of a given factory, reduce fixed costs per unit.

b) Industry, in particular, may enjoy scale advantages, in that the smaller manufacturing unit within the reach of a public system usually has the option of connecting to that system when the

TABLE 7

ESTIMATED INVESTMENT FOR WASTE TREATMENT WORKS 1952-1968*

Source of Investment	Aggregate Investment 1. Million of Dollars
Public Agencies in SMSA's	8,549.3
Public Agencies, Non-SMSA	1,953.7
Manufacturing Plants (estimate)	3,619.8
TOTAL	14,122.8
	2. Dollars Per LB. of 1968 BOD_5 Removal
Public Agencies in SMSA's	336.59
Public Agencies, Non-SMSA	465.17
Manufacturing Plants	73.42
Total	179.00
	3. Dollars Per LB. of 1968 BOD_5 Removal, Excluding Transmission
Public Agencies in SMSA's	102.40
Public Agencies, Non-SMSA	338.60
Manufacturing Plants	73.42
TOTAL	96.52

* Excludes Collecting Sewers

cost of separate treatment appears to be greater than that of joint treatment. In increasing measure, the same mechanism is being utilized by metropolitan area communities. The decision to install separate treatment or to cooperate with one's neighbors becomes available to a community where population is sufficiently concentrated in a given area; and the lack of such options forces the outlying community (or factory) to provide treatment at a relatively high cost.

c) The higher transmission costs characteristic of metropolitan areas are an obvious consequence, indeed, the precondition, of lower treatment costs. Use of larger waste treatment plants requires transmission of wastes over longer distances or in greater volumes.

d) Industry, viewed in the aggregate, not only enjoys the advantage of choice of technology and location, but combines with it low relative unit transmission cost. Proprietary treatment plants are almost invariably located at the factory site, so that sewering to the treatment plant is apt to cost little more than for untreated disposal. And when industry has the use of a public system available to it, it tends to occur within a format of developed waste transmission service, so that it may cost no more to transport the wastes of a factory to the plant site than it does a single household.

e) The apparent unit investment advantage enjoyed by industry is exaggerated by an accident of time. Where a substantial portion of the nation's stock of public waste treatment works dates back to the nineteen-thirties, and a few units are even older, waste treatment had only begun to be a factor in industrial planning by the late nineteen-fifties. Essentially all of the industrial treatment projects that have been undertaken over the last decade are first generation facilities. In contrast, a very significant part of public capital spending has had to be devoted to replacement and improvement of existing facilities. Expenditures of substantial sums that result in no incremental waste reduction lend the appearance of high relative cost to public works as compared to industrial ones, but the disparity may be expected to disappear progressively over the course of the next decade, as American industry becomes involved in the replacement and improvement process.

The Influence of Federal Construction Grants

The expansion of waste treatment services over the last decade and a half is hardly conceivable without the intervention of Federal monies. Per-capita investment has doubled since enactment of Federal grants, and with time, the amount and the proportion of total public spending provided by Federal government has increased steadily. In consequence of the availability of the Federal funds, not only the prevalence of waste treatment but the nature of its application has changed. Interjection of large sums would appear have worked a qualitative as well as a quantitative change in the conduct of public waste handling services; and the scale of the problem-solving effort has enlarged so much as to effectuate a transformation of its character.

Rapid extension of sewer services, cooperative utilization of facilities by groups of communities, long-distance transmission lines, public treatment of industrial wastes, and the development of area-wide sanitary authorities may all, in some measure , be considered to be correlates of Federal investment. For with the availability of Federal assistance there has come an enlarged sense of the scope of the water pollution problem, and a more aggressive and imaginative public approach to the problem.

But much of the force of Federal financial assistance still remains to be felt. Amendment of Public Law 660 has resulted in a progressively larger Federal share of the total cost of waste handling projects, and has elicited additional matching funds from State government. It is possible to argue that these funds are entirely responsible for expansion in public waste handling practices over the last decade: for while total public investment for waste treatment advanced from $350 million on 1956 to well over a billion dollars in 1970, local government's share of the capital has remained fairly constant at about $300 to $400 million a year*. Federal monies--including claims on still unappropriated funds available under the reimbursement provisions of PL 660--and those of State governments are essentially responsible for expansion.

Even given the situation that local expenditures for waste handling services are relatively constant, so that higher Federal and State outlays translate without a multiplier into new projects and ultimately into new works, the massive interjection of Federal monies currently being experienced in the market for waste handling facilities is sufficient to work an enormous alteration not only on the scale of water pollution control, but in its very substance. Appropriations for waste treatment plant construction grants in 1970 amounted to almost two-thirds of cumulative Federal appropriations for the purpose to that time, and exceeded the level of cumulative cash outlays (made in the form of progress payments) during the entire fourteen year life of the assistance program. Further, California, Oregon, Kansas, Ohio, and Illinois followed the lead of other States and initiated or implemented State fund-matching programs to enable them to take full advantage of the enlarged availability of Federal capital. As described later, even a $200 million level of Federal funds has been absorbed into the economy only with the accompanying appearance of some very inefficient resource allocations; and there is some question as to the utility of a good portion of the expenditures made to date. The development of mechanisms to effectively utilize larger amounts of Federal funding will pose one of the significant public policy problems of the 1970's.

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*Correlation of total value of PL-660 eligible contracts, Federal Grants, and volume of local government bond financing indicates a $302.7 million local government annual spending base (standard deviation $65 million) during the life of the Federal Assistance program.

Another aspect of the impact of Federal construction grants on municipal pollution abatement capabilities makes it difficult to anticipate effects. The funds are devoted to major public works, that are usually among the most costly and the largest capital facilities operated by local government. As one would anticipate, significant lags are involved in their installation. The mean time lapse between the award of a Federal construction grant and the initiation of construction is 15 to 18 months, and an even longer period is devoted to actual construction. Those lags are responsible for the growing gap between Federal grant awards and actual disbursements. Time elapsed between the initiation of a project and its completion tends to be increased by the Federal allocation formula, which establishes each State's initial entitlement to grant assistance on the basis of population and income. In the past, there have consistently been States that could not allocate a year's full entitlement to funds in the same year; and the small list of States whose needs were not sufficient to take up allocations at a $100 to $200 million level will unquestionably expand at the much higher assistance levels proposed for the nineteen-seventies.

Time lags interfere, too, with our ability to gage the effect of Federal construction assistance. In the early years of the grant program, dollar amount limitations and specific reservation of a significant segment of Federal funds for the use of small communities sharply reduced the reach of assistance. In general, application of Federal funds was limited to rather simple engineering projects whose scale and complexity seldom involved extended periods of construction. In consequence, little more than half of the value of waste treatment projects undertaken in the first years of the Federal program involved Federal assistance, and mean construction time for those that

TABLE 8
FEDERAL CONSTRUCTION GRANTS RELATED TO PUBLIC CONSTRUCTION ACTIVITY

	Millions of Dollars				% Fed'l	
Year	Total value of Contracts	Fed'l Grant Appropriations	Fed'l Grant Awards	Federal Disbursements	Apptns. Basis	Awards Basis
1957	351	50	38	1	14.3	10.8
1958	389	45	48	17	11.6	12.3
1959	349	45	46	36	12.9	13.2
1960	359	46	49	40	12.8	13.7
1961	449	46	45	44	10.2	10.0
1962	545	80	66	42	14.7	12.1
1963	679	90	93	52	13.3	13.7
1964	514	90	85	66	17.5	16.5
1965	522	93	84	70	17.8	16.1
1966	553	121	120	81	21.9	21.7
1967	597	153	134	84	25.6	22.5
1968	652	203	194	122	31.1	29.8
1969	865E	214	203	135	24.7	23.5
TOTALS	6824	1276	1205	790	18.7	17.7

did was about two years. But with larger amounts of Federal grant appropriations the dollar amount limitations were removed entirely, and the effective force of the fixed value reservation for use of small communities was dissipated. Since 1966, almost every municipal waste treatment project has involved PL 660 funds; and over the last three years, the value of Federally assisted new starts has exceeded the value of total contract awards--an anomally produced by the reimbursement provision of PL 660, as well as by time lapsed between the award of a contract and the start of construction. In the future, it is probably safe to assume that as long as Federal construction assistance is available, no community will begin a waste treatment project without the assurance of Federal grants.

With the expansion of the scale of projects for which Federal funding has become available, the time to completion of such projects has steadily extended. The 1968 conditions evaluated at some length in this report include the effects, on average, of construction projects begun in 1966. The much greater rate of activity initiated in 1970 will not be translated into average effects until 1973 or 1974.

Considering the entire life of the Federal program of assistance for construction of waste treatment works, about half of the value of all construction projects initiated between 1957 and the end of October 1970 had actually been completed. (cf. Table 9. Adjusting for inflation makes some difference, since the amount of resources expended has increased as their purchasing power has declined; but even with the adjustment, almost 40% of the total value of projects undertaken with the assistance of PL 660 grants represented works still under construction in the third quarter of 1970.)

Capital Overhead

One sometimes receives the impression, from popular commentary on the water quality situation, that great volumes of untreated municipal sewage are being discharged into the nation's waters, and that these are a significant source of water pollution. In point of fact, only seven percent of the sewered population of the U. S. was discharging raw wastes in 1968; and the figure is probably closer to five percent today. Moreover, both treated and untreated municipal wastes are currently estimated to be responsible for little more than 20% of stream pollution, as discussed in a later section of the report.

It would be a mistake to infer from those relationships that capital requirements are subsiding. While there is definite room to complete the provision of waste treatment service, to upgrade the level of waste treatment effectiveness, and to accomodate expansion requirements, there is also a need to service the very considerable capital

TABLE 9

ANNUAL VALUE OF FEDERALLY ASSISTED WASTE TREATMENT WORKS CONSTRUCTION

	Value of Federally Assisted Projects Millions of Dollars				
Calendar Year	New Starts	Completions	Under Const. @Year End	Cumulative Completions as a % Starts*	Lag in Months, Starts= Completions*
1957	165	5	160	2.9	-
1958	184	65	279	20.1	-
1959	173	142	310	40.6	27
1960	203	166	348	52.1	23
1961	248	172	423	56.5	21
1962	291	160	554	56.2	22
1963	449	193	811	52.7	26
1964	443	402	843	60.8	24
1965	365	340	868	65.4	34
1966	490	398	960	68.0	34
1967	397	265	1091	67.9	37
1968	765	194	1662	60.1	43
1969	937	375	2224	56.4	46
1970	1135**	158**	3201**	49.2**	48**
Cumulative	6164	3035			

* Federally Assisted projects only

** 10 months, January 1970 through October 1970 base already in existence. That overhead demand on capital has for some years been the prime features of public waste treatment investments. Yet it has generally been overlooked.

At the levels of capitalization of the nineteen-sixties, recapitalization projects absorbed most of the waste treatment investment made by public agencies. That--though in lesser measure than the fact that municipal waste management is directed to only a part of the total water pollution problem--is a reason that public expectations have been disappointed. To deal with the complexities of public wastewater management, it must be recognized that most of the necessary capital base already exists, that its very existence creates a significant demand for capital services, and that great damage can result if we allow the existing system to deteriorate.

The dimensions of the overhead demand for replacement capital have been quantified. Replacement values of waste treatment plants in place in 1962 and 1968 were calculated, giving full weight to scaling and technological differences, in terms of constant (1957-59) dollars; and the values were compared to constant dollar investment over the period. Approximately $2.1 billion of investment in waste treatment works (interceptor sewers, outfalls, and pumping stations are excluded from the analysis) produced only $780 million worth of additional physical capital. The difference between the investment amount and the capital increment may be considered to constitute the value of recapitalization of existing works that took place over the period.

As presented in Table 10, where recapitalization or depreciation is expressed as the difference between the annual rate of investment and the annual rate of expansion of the capital base, recapitalization demand amounted to 4.4% of replacement value of fixed capital over the period. If depreciation is calculated on the basis of the average rate of depreciation of a moving capital stock, the rate amounted to 4.1% a year. Both values are very close to the design norm of 4% a year utilized by the sanitary engineering profession. That general agreement would seem to provide some confidence about the magnitude of waste treatment plant recapitalization requirements for any given capital stock, if one assumes that relative shortage of available capital did not constrain recapitalization expenditures to something below an optimum rate. On that matter there can be no assurance until the aggregate level of investment moves distinctly upward, to allow some scrutiny of the distribution of investments in a more generously funded condition set.

It may be noted that while the national rate of depreciation is very close to the 4% norm, there is distinct regional variation. Two factors may be considered to be operative. The age composition of

TABLE 10
EFFECTIVE RATE OF RECAPITALIZATION, 1962-1968
(WASTE TREATMENT PLANTS ONLY)

	Millions of 1957-59 Dollars			Annual Rate		
Region	1962 Capital	1962-68 Investment	1968 Capital	Investment	Capitalization	Indicated Depreciation
Pacific Coast	364.8	185.2	474.3	6.0%	3.8%	2.2%
Northern Plains	297.5	210.0	363.0	8.0%	2.2%	5.8%
Southern Plains	503.2	177.3	594.0	4.4%	2.4%	2.0%
Southeast	507.7	383.3	710.0	8.2%	4.9%	3.3%
Central	698.3	502.4	869.9	8.1%	3.2%	4.9%
Northeast	566.4	589.4	725.8	10.9%	3.6%	7.3%
U. S.	2938.3	2056.5	3719.9	7.9%	3.5%	4.4%

waste treatment plants varies from area to area; and the higher the average age, the greater the effective rate of depreciation. The other consideration is something of a mathematical fluke. Replacement value of plants at either period was calculated on the basis of national average costs, and so should conform closely to the national distribution of investment in facilities. There are, however, extreme variations in design and construction efficiency from region to region. (cf. *The Economics of Clean Water*, U.S.D.I., FWQA, March 1970, pp. 40-52.) Without exception, the higher than average depreciation rates occur in high cost regions, the lower than average depreciation rates occur in the low cost regions. Thus when the analysis moves from the national total to a region, what is presented as depreciation or recapitalization is a compound of recapitalization and efficiency differentials that apply in the construction activity. In part, comparision of the 7.3% indicated depreciation rate for the Northeast with the 2.2% rate of the Pacific Coast weighs the fact that it costs considerably more to build a waste treatment plant in New York than to build a similar plant in California.

TREND OF WASTE DISCHARGES

One possible measure of the effectiveness of State and Federal water pollution control programs and expenditures is a comparison of the amounts of sewered waste materials flowing into waterbodies over time. It must be recognized that the test is by no means a satisfactory one--too many elements other than collected wastes bear upon the quality of water. Such a comparison, however, does have considerable validity as a measurement of capital efficiency, in that the primary emphasis of the nation's water pollution control efforts has been to increase the degree of treatment of collectable wastewaters; and that activity has been very nearly the exclusive avenue for investment of funds intended to serve water quality purposes.

Unfortunately, there is no set of records to provide such a comparison on a macroeconomic basis. It is possible, however, to synthesize the information by calculating estimated waste production and discharge at different periods.

Performance of the calculations for two significant waste constituents, biochemical oxygen demand and dissolved phosphorus, at three points in time is scarcely,reassuring. The estimates indicate that the gross oxygen demand of wastes discharged in 1968 was almost unchanged from--and probably slightly larger than--the level of 1957; and that in the same period, the total pounds of phosphorus discharged with domestic sewage had more than doubled. Almost $15 billion of public and private monies were invested in waste handling facilities during that period--and as a consequence of that investment, annual operating charges increased by about $300 million.

Biochemical Oxygen Demand

Five day biochemical oxygen demand (BOD_5) is probably the most useful general indicator of the strength of organic wastes. It is the measure of the amount of oxygen utilized in a fixed period of time and at a fixed temperature by the biological processes involved in the stablization of organic matter. In itself it provides a very useful measurement of the strength of organic wastes or the amount of organic material present in a stream at any point in time. It is also an extremely useful indicator of the general quality of a waterbody, in that it has a loose and varying but largely dependable sort of association with other water quality measurements. It most cases we can assume that a stream with a high concentration of BOD_5 is apt to be marked by some lowering of concentrations of dissolved oxygen, a significant chemical oxygen demand, and elevated levels of bacterial presence. For this reason--and because there are standardized, generally accepted tests for BOD--it is the most widely used means of expressing, in almost shorthand fashion, the general quality of water; and it is accepted by sanitary engineers if not ecologists as a surrogate for other parameters in broad descriptions of waste characteristics or of stream quality. However useful this measure is in describing overall quality, one cannot in actual fact rely solely on it in specific cases of pollution. It does not comprehend such significant pollutants as mercury, pesticides, and other toxic and hazardous substances.

Because of its well established position as the prime measurement of waste strength, BOD reduction is the standard indicator of waste treatment plant efficiency, and the municipal waste inventories provide an excellent guide to the oxygen demand of public wastes; but it must be admitted that the estimates of industrial production and discharge of BOD present in the tables that follow are gross approximations. The technique employed to calculate production of BOD by manufactures involved the application of the ratio of the 1964 to the 1957 and the 1968 Federal Reserve Board Indices of physical production for various industrial sectors to annual waste reproduction calculated for the same industrial sectors in 1964. (The base data are summarized in Table II-2, p. 63 of The Cost of Clean Water, USDI; Washington, D. C., January, 1968.) The principal problem with the method--given the validity of the industrial production indices and the calculated base year wasteloads--is the assumption of a constant waste to output ratio. The assumption is crude, but the fact is that there is not sufficient information to attempt modification. (A variety of recent events indicate that more adequate industrial waste information will be available to the Environmental Protection Agency in the coming year. Results of a questionnaire survey conducted for the Agency by the National Industrial Conference Board will be forthcoming in the next months. The survey is designed to provide information on current and expected waste control practices and expenditures. The questionnaire is reproduced as Appendix A.

(In the late 1970, approval was gained to initiate an industrial waste inventory, on a national basis. A preliminary mailing of 250 questionnaires has been made to develop base information on anticipated response rates and completeness of data.

(Activities related to implementing the Permit Program under the 1899, Refuse Act (33 U.S.C. 407) as called for by the President in Executive Order 11574, December 25, 1970, will shed further light on the industrial situation. Contracts for industry studies of those industrial sectors generating over three fourths of the total volume of wastes discharged directly by industry have been let. These contracts will produce guideline data on the most prevalent methods of industrial waste reduction as well as assessing the best waste reduction available with current technology.

The permit applications themselves will provide an unequalled and hitherto unavailable source of information on the magnitude, distribution and remedial needs of the industrial community.

(These coordinated efforts should essentially provide a quantum increase in useful information for assessing and evaluating all aspects, both physical and economic, of the industrial pollution abatement problem.)

Gross production of BOD is only a portion of the picture. Pollution results from the strength and nature of wastes that are ultimately discharged. From the estimates of waste production we must deduct that portion of the polluting materials that is reduced by treatment. The gross effectiveness of industrial waste treatment was calculated from the ratio of investment capital in place to total estimated capital requirements for each industrial sector. (Estimated capital requirements for 1964 and 1957 were assumed to be equal to the 1968 capital requirement,* modified by a factor equal to the production index for the given year divided by the 1968 production index. Capital in place in 1957 and 1964 was derived by deducting from the 1968 calculated replacement value, reported annual capital inputs, after subtracting four percent of each year's capital in place--the four percent figure intended to eliminate replacement/depreciation expenditures to arrive at a value for net capital.) Treatment effectiveness, then, is expressed in terms of the proportion of the optimum capital supply available in aggregated industrial sectors at points in time. The optimum capital supply, by a loose interpretation of the definition established by the guidelines used to adopt interstate water quality standards, is that which is required to achieve 85% reduction of BOD_5.

Adjustment of the industrial waste load to account for that portion of industrial wastes that is sewered to public waste treatment facilities probably imparts a slight downward bias to the calculated degree of BOD reduction, because there is no accounting--from either municipal or industrial sources--of the sectoral distribution of the industries discharging to public facilities. It is possible to estimate with some degree of precision just how much industrial waste is handled by public facilities, but not what industries develop those wastes. To produce a comprehensive BOD model, then, it is necessary to work at the aggregate level, deducting from the total industrial load that portion which can be assigned to municipal or other public sources. Possible distortion in attributed efficiency of the self treating component occurs because the capital effectiveness of the treatment dollar varies between industries, due to scale factors and differences in waste composition. The distribution of total wastes

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* As developed in THE COST OF CLEAN WATER

and of costs is, however, so strongly influenced by a few industries (pulp and paper, organic chemicals, oil refining) that average costs are in effect little more than the average costs that apply to the preponderant group of industries. The sensitivity of over-all efficiency to the sectoral incidence of use of public facilities is, then, probably very slight. The 61% aggregate BOD_5 reduction efficiency calculated to apply to independently discharging factories in 1968 changes little more than 2.5% in either direction when one calculates the effect of consigning either the most capital-efficient block of industries or the least capital-efficient group entirely to the segment of plants making use of public facilities.

Determination of the discharges of public waste handling systems involves much less uncertainty than do attempts to estimate the same values for industry. The Municipal Waste Inventory provides us with a knowledge of the number, kind, size, and served population of waste treatment plants, as well as the number and service population of sewer systems without waste treatment service. A couple of thousand investigations of waste treatment plant operations provide a solid grasp of the range of waste loadings and the range of efficiencies associated with treatment plants of various sizes and types. By applying appropriate loading and reduction rates to the reported stock of waste handling systems, the order of magnitude of the wastes that pass through the nation's system of public sewers can be ascertained with considerable confidence.

If the validity of the data can be accepted, the largest problem in framing an estimate of publicly discharged wastes is distinguishing between domestic and industrial sources that are served by the same set of facilities. While modern data imply strongly that the rule of thumb which holds that the characteristic relationship of one hundred gallons of water and one-sixth of a pound of BOD per person overstates the "normal" domestic wasteloading, the latter value has been adopted in assessing the total domestic wasteload. The relationship has been accepted so generally and so long that its use has the great merit of reducing possible objections. And in view of the uncertainty associated with estimating the gross volume of factory wastes, a slight understatement of their proportionate share of the use of public systems does not seem to offer a problem of relative moment.

The sets of products of the various calculations are presented in Table 11.

While the details and the precision of the listed values may be subject to considerable suspicion, there is little reason to doubt the general validity of the relationships or the order of magnitude of the values. The story that they tell is not reassuring one for those concerned with environmental protection.

TABLE 11
ESTIMATED INCREASE IN GROSS PRODUCTION OF BOD$_5$, 1957-68

	Millions of Pounds of BOD$_5$ Per Year				
				Increase	
Waste Source	1957	1964	1968	1957-64	1964-68
Food Processing	3400	4300	4600	900	300
Textile Mill Products	660	890	1100	230	210
Paper & Allied Products	4300	5900	7800	1600	1900
Chemical & Allied Products	5500	9700	14200	4200	4500
Petroleum & Coal	410	500	550	90	50
Rubber & Plastics	20	40	60	20	20
Primary Metals	350	480	550	130	70
Machinery	100	130	180	30	50
Transportation Equipment	50	120	160	70	40
All Other	300	390	470	90	80
Manufacturing Total	15,090	22,460	29,670	7370	7220
Sewered Population	5,700	7,600	8,500	2100	900
TOTAL	20,790	30,060	38,170	9470	8120
Annual Rate				5.4%	6.2%
Reduced by Treatment	8,090	14,090	24,610	6000	10,520
Annual Rate				8.2%	15.0%
Discharged	12,700	15,970	13,560	3270	-2410
Annual Rate				5.9%	-4.2%
Aggregate Treatment Efficiency	39%	47%	64%	21%	36%
Ratio of Domestic to Industrial BOD	1:2.6	1:2.9	1:3.5	1:3.9	1:8.0

The gross biochemical oxygen demand generated in the collectable wastes of economic activities almost doubled between 1957 and 1968. Within the period, the process took place at an accelerating rate--increase in waste production for the four years 1964 to 1968 almost matched the total increase that took place in the seven previous years.

Manufacturing activities--paced by production of chemicals and chemical products, estimated by 1968 to account for more than a third of total BOD production--far outweighed domestic activities as waste sources in 1957, and steadily increased their lead with the passage of time. That rapid growth of industrial wastes traces not only to the raw increase in industrial production that occured during the period, but to its composition. The economy of the U. S. has been marked not only by a voracious absolute demand for more goods, but by a relative preference for goods whose production involves a substantial wasting of organic materials to water.

Countering the increase in volume of organic wastes has required an enormous expansion of the prevalence and intensity of waste treatment. While total wastes, as measured by BOD_5, almost doubled in the period under consideration, the amount of reduction of oxygen demand through the application of waste treatment is calculated to have tripled. Overall, then, there appears to have been only a slight increase in the oxygen demand exerted on the nation's water resources as a result of the discharge of collected wastes. And since 1964, the rate of change in the oxygen demand of waste discharges has been strongly negative.

Nutrient Phosphorus

Streams, lakes, estuaries and their beds are in many instances producing rooted and floating flora in such profusion that they cause nuisances or profound alteration in aquatic ecology. The condition clearly relates to some significant set of changes in the circumstances that govern the life processes of aquatic organisms. But since many conditions have changed, there is no certainty as to what the critical productive mechanism may be. Increased clarity of waters as a result of sediment control and reduction of wastewater solids results in increased light penetration, clearly favorable to vegetable productivity. Escalation of the gross volume of materials discharged to water adds to the availability of all of the elements that nourish life forms. Heightened temperature--a result not only of heated waste discharges but of stream impoundment and reduction of streamflow--accelerates the life cycle processes of growth and decay. And there are known to have been substantial increases in the discharge to water of specific nutrient materials critical to the life forms involved.

Explanations and control efforts, however, have been directed increasingly toward the relative availability of a single nutrient element, phosphorus. Underlying the attention to phosphorus are a set of probabilities derived from the law of the minimum. The hypothesis is supported by evaluation of production factors bearing upon the relative availability of phosphorus in water, by observations drawn from knowledge of the characteristics of treated wastewater, and by controlled laboratory demonstrations. It would seem probable that phosphorus is, indeed, a key to problems posed by extremes in aquatic productivity.

In the context of a shift in all, or many, of the factors that affect biological productivity in water, investigators have attempted to deduce the most likely avenue for control by use of observations based upon the law of the minimum--a logical principle that holds that where more than one condition must be satisfied in order to produce a given event, that condition which is least abundant with reference to demand requirements will determine the magnitude of the consequent event.

In the case of algae and other water plants, the conditions required for development are the presence of energy in the form of sunlight and a supply of nutrient materials, principally carbon, nitrogen, and phosphorus in the approximate relationship (for algae) of 106:16:1. (Other nutrient elements are required in trace amounts, but the insignificant quantities involved defeat any possibility for effective biological controls.) Because algae can normally satisfy carbon requirements from carbon dioxide in the atmosphere and from the natural carbonate in water, efforts to control aquatic production settled very early upon nitrogen and phosphorus. Recognition of the fact that blue-green algae, and perhaps other types as well, can also draw nitrogen from the atmosphere, led to the conclusion that attempts to control growth solely by limiting availability of dissolved nitrogen in water would also be of little purpose. By process of elimination, then, attention has come to focus on phosphorus; and observations about the gross availability and the form of dissolved phosphorus strengthen the probability that it is the route to controlling the increased productivity problem.

There is no question that the gross increase in waterborne wastes has resulted in a significant increase in total amounts of dissolved forms of carbon, nitrogen, and phosphorus. But because of atmospheric availability of the others, only phosphorus can be considered to have experienced an increase in usable supply from waste discharges. Further, the relative availability of phosphorus to biota has been supplemented by the extension of secondary waste treatment.

The relationship between the prevalence of secondary waste treatment and relative availability of phosphorus is well understood, but often ignored because of its embarrassing conflict with other water pollution control requirements and prevailing strategies of water pollution control. Conventional waste treatment reduces the quantity of phosphorus dissolved in wastewater. But the average relationship of carbon to nitrogen and phosphorus utilization by the bacterial organisms that accomplish conventional waste treatment permits only a fraction of the nitrogen and phosphorus of sewage to be incorporated into sewage sludges; so that the major portions of these wastewater constituents remain in the discharged effluent. Furthermore, while biologic treatment reduces fractionally the amounts of nitrogen and phosphorus in sewage, it also stabilizes them, so that they are contained in the effluent in a form immediately available to fertilize growth. In the case of an untreated waste, or one subjected to only primary treatment, the discharged effluent also contains nutrient materials but in a organic composition, so that they become available to algae only as natural decomposition occurs.

The whole process has been accelerated by another factor, the replacement of soap by phosphorus-based synthetic detergents. Where human metabolic processes are variously estimated to result in the wasting of from less than a pound to about a pound and a half of phosphorus per person per year, average phosphorus loadings in municipal wastewaters during the late nineteen-sixties were consistently found to be equal to about four pounds per person per year. Most of the difference has been attributed to the sewering of used detergents.

To heighten problems of phosphorus availability, a significant change in detergent formulations was accomplished during the early nineteen sixties. Previously, detergents had demonstrated a distressing tendency to resist decomposition in either waste treatment plants or in the natural environment. Due to the slow stabilization of the compounds, foaming and discoloration became evident in many streams as consumption of detergents increased. Steps to abate that water pollution problem contributed to the creation of the problem of excessive productivity. The detergent industry was able to develop formulations that suffered no reduction in cleansing power, but broke down readily in waste treatment plants. That stabilization made the phosphatic constituents of wasted detergents available as aquatic nutrients. To add to the dimensions of the problem, "soft" or "biodegradable" detergents typically contain significantly more phosphorus per pound than the " hard" formulations that they replaced.

Such, in very general terms, are the qualitative dimensions of the matter as they are defined by what has come to be the conventional wisdom. Its quantitative aspects are not so readily manipulated. Evaluations must rely on limited samples, general acceptance of some provisional relationships, and some functional derivations. Those circumstances mean that only order of magnitude accuracy can be claimed for the following analysis. It is unlikely, however, that greater precision would serve any useful purpose in this report. Remedial actions must take place in the context of conditions that apply in discrete river basins. At the level of macroeconomic overview, consideration of relative magnitudes over time would seem to provide a sufficient and credible level of detail.

Table 12 presents such a generalized description. While it must be emphasized that unit values for phosphorus content represent fairly arbitrary choices from ranges of cited values for influent and effluent wastewaters, the calculated net per-capita discharge of 3.3 pounds per year agrees generally with the value of 3.5 pounds per-capita per year estimated by the International Joint Commission in its report on Lake Erie and with values reported by the Committee on Government Operations in its report Phosphates in Detergents and the Eutrophication of America's Waters. Estimated reduction of phosphorus by waste treatment processes is a particularly uncertain element of the system. Reductions are generally expressed in the literature in percentage terms, and the number of citations is depressingly slim--over half of the reported values from which the tabular data were deduced came from one survey in the State of Texas. The logic of the values presented depends on the concept that phosphorus reduction is a function of biochemical oxygen demand reduction, in that utilization of phosphorus is dependent on the degree of stabilization of dissolved organics in wastewater. The amount of phosphorus utilized in decompostion processes is largely dependent on the total quantity of organic matter stabilized rather than the amount of available phosphorus, given that phosphorus is available in amounts equal to or greater than nutrient requirements, so that percentage expression is considered to be an inappropriate means of gaging relative effectiveness in phosphorus reduction. (Complete elimination of dissolved phosphorus in domestic sewage is theoretically feasible at the point that concentrations in influent wastewaters are equal to nutrient requirements of bacteria).

There can be no doubt that industrial utilization of detergents as well as direct processing of phosphate and phosphorus products adds to nutrient availability, but there is simply not enough information to even attempt to make an estimate of quantities. Natural sources--decomposition products, resuspension of bottom muds, leaching--as well as mining and agriculture add to the gross quantity of phosphorus transported in water. To a considerable extent, however, these sources are reduced in their ability to produce excessive growth by the propensity of phosphorus to be adsorbed by soils. So contained, phosphorus can be released to the water column through decomposition of rooted bottom plants. For these reasons, remedial attention has been devoted largely to phosphorus in sanitary sewage.

Sources of Waste Increases

Biochemical oxygen demanding materials and nutrient phosphorus are only two of the scores of possible pollutants with which the economy must deal. They have been selected for quantification and discussion because they are most amenable to generalized analysis, and because they serve to illustrate principal features of existing control programs. But it relative magnitudes over time would seem to provide a sufficient and credible level of detail.

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TABLE 12

ESTIMATED INCREASE IN PHOSPHORUS DISCHARGED AS MUNICIPAL SEWAGE

	1957	1964	1968
Sewered Population (Millions of Persons)	98.4	119.6	139.7
Per-capita Phosphorus Production, Pounds:			
a) From metabolic process	1.0	1.0	1.0
b) From consumption of Detergents	2.0	3.0	3.3
Total Sewered Phosphorus (Million pounds in year)	295.2	478.4	600.7
Less Phosphorus Incorporated in Sewage Sludge:			
a) Primary treatment @ .5 lbs. per capita (million pounds in year)	(12.9)	(20.4)	(21.8)
b) Secondary treatment @ 1.3 lbs. per capita (million pounds in year)	(63.6)	(81.3)	(111.8)
Total Discharged Phosphorus (Million Pounds in Year)	218.7	376.7	467.1

should not be inferred that they are the only significant causes of pollution. Rather, they are convenient indicators of the dimensions of pollutant production and of the relative magnitude of pollutant sources. And while a broad group of pollutants and activities remains outside of the reach of current technology, traditional sewered sources of pollution such as solids, bacteria and BOD should be receding before the application of waste treatment.

But even in their cases, there may be doubts about our ability to maintain existing relationships between the rate of increase in waste generation and the rate of expansion in effectiveness of waste treatment. If the same processes were to continue into the future at the rates that obtained between 1957 and 1968, at some point in 1974-5 we would have reached the approximate threshold of waste treatment effectiveness that is attainable with conventional technology--85% to 90% BOD reduction. From that point forward, residual waste strength might be expected to add in full measure to the polluting pressures exerted on the national water resource; and in the 1980's that steadily increasing wasteload would again attain, then proceed to exceed, the peak levels of 1963 or 1964. (See Table 13). These considerations are not presented as a prediction, but only as a projection of the circumstances that will come into play in the future if substantial structural changes are not affected in ecological postures. Of course, current conventional waste treatment technology is in no way an ultimate barrier. Advanced water treatment techniques are available being refined, and coming into increasing uses. But technological shifts in water treatment tend to occur as series of step functions; and each translation to a higher step would seem to at least double the aggregate cost of treatment. Moreover--and perhaps most significant--waste treatment, regardless of its cost, is not an absolute good. There are secondary effects, not always foreseeable or beneficial, when one tampers with the quality of water in order to produce obviously desirable purposes.

The tentative conclusion that waste treatment is no more than a convenient point of departure for any meaningful strategy of water pollution control is reinforced by examination of the sources of recent increase of pollutants. Underlying the growth of available biochemical oxygen demand and of phosphorus are basic economic forces. To counter the polluting effects of fundamental features of twentieth century technology and social organization would seem to call for fundamental remedies.

TABLE 13

PROJECTED INTERACTION OF TECHNOLOGICAL LIMITS AND EXISTING RATES OF WASTE INCREASES

Year	Million Pounds of BOD Per-Year Produced	Reduced by Treatment At 85%	 At 90%	Discharged At 85%	 At 90%
1968	38,170	24,610		13,560	
1972	47,560	36,915		10,645	
1974	53,120	45,220		7,900	
1975	56,150	47,730	50,535	8,420	5,615
1976	59,260	50,370	53,330	8,890	5,930
1980	73,840	62,760	66,460	11,080	7,380
1984	92,000	78,200	82.800	13,800	9,200
1988	114,630	97,440	103,170	17,190	11,460
1992	143,290	121,790	128,960	21,500	14,330

Total Increase:

Between 1964 and 1968, the population of the U. S. was estimated to have increased from 191.4 million persons to 199.9 million persons, about 4.4% or just under 1.1% per year. During the same period, estimated annual production of biochemical oxygen demand advanced by a total of 8.1 billion pounds, or 27%, six times as fast as population, compounding at a 6.1% annual rate. And while the increase in the phosphorus content of sanitary sewage was not so great in absolute amount, an estimated 122 million pounds over the four years, it was equal in relative terms, rising almost 26%, an annual rate of increase of 5.9%.

Population Increase:

Population increase is, of course, related to the increase in production of pollutants, but it can by no means account for major part of the growth. If expansion of sewered domestic wastes had been directly proportionate to population growth, the rise in BOD of sanitary sewage would have amounted to 330 million pounds between 1964 and 1968, and the increase in the phosphorus component of sanitary sewage would have been limited to 23 million pounds. Expansion of industrial output to accommodate increased population at precisely the level and compostion of per-capita consumption of 1964 would have added about 990 million pounds a year to BOD production by 1964. Pure growth of population, then, can be assigned the responsibility for no more than 16.3% of the gross expansion of BOD production and 19.1% of the incremental phosphorus production took place over the four year period.

Expansion of Sewer Service:

The effects of population increase on production of water-borne pollutants were heightened by a pronounced expansion of sewer service. Where population grew at 1.1% annual rate, sewered population increased at a 2.8% annual rate, so that an incremental 570 million pounds a year of BOD and 33 million pounds of phosphorus had become available through the expansion of sewer services by 1968. The application of conventional sanitary engineering in the form of expansion of sewer service offset about half of the gain in reduction of BOD of sanitary sewage that was effectuated by increasing the prevalence and intensity of waste treatment during the period. It caused a net loss in the degree of phosphorus control, in that incremental phosphorus reduction--not a significant feature of conventional waste treatment--was well under the volume of phosphorus in the water-borne sewage produced by net expansion of sewering. Seven percent of the total increase in BOD and 27% of the growth of phosphorus in domestic sewage between 1964 and 1968 can be traced to extension of sewer services in excess of the rate required to match population growth.

Gross Increase in Consumption:

The lion's share of responsibility for rise in production of pollutants must go to the gross improvement and the distribution of per-capita production and consumption of goods that took place during the four years. Almost 77% of incremental BOD production and 53% of the increased discharge of phosphorus to sewers can be traced to the amount and composition of rising consumption of goods by Americans. Significantly, much of that production can not be considered to have improved the real economic well being of consumers. Twenty-three percent of the total increase in BOD occurred as a result of the growth of pulp and paper output, where more elaborate packaging has provided much of the impetus for growth. Similarly, no less than 55% of the larger output of BOD arose from chemicals production; and an indeterminate but large portion of that increase must be ascribed to expanding use of various disposable products. In the same general way, an estimated 42 million pounds of sewered phosphorus can be ascribed to increased utilization of phosphorus in detergent formulations--an increase in unit use that was again reinforced after 1968 with the appearance of phosphorus-rich "enzyme" pre-soaks and detergent compounds.

Disposition of Waste Increases

The more than 8 billion pounds of biochemical oxygen demand that were added to the annual waste production of the American economy between 1964 and 1968 represented not only an enormous potential to pollute water, but a significant materials handling problem. Eight billion pounds of BOD, given mean concentrations, implies the discharge of more than 4 trillion gallons of wastewater annually, well over 13 billion gallons per day. Quite apart from the matter of abating the polluting effects of materials carried in wastewater, the very volume of the water being discharged under conditions of unrestrained growth of wastes creates a source of continuous pressure on capital. For every dollar that was invested by public agencies for waste treatment, more than $1.75 had to be invested in waste transmission facilities--for metropolitan areas it was $2.37--and 75¢ was invested for collecting sewers. In reviewing the situation, one cannot help but wonder if the exigent pressures posed by the need to simply drain away the wastes of our cities are not so great that they divert a significant amount of the resources intended for water pollution control for purposes of simple waste disposal.

In terms of relative strength, manufacturing was responsible for almost 90% of the increase in BOD that occurred in the period. However, manufacturing outfalls are estimated to account for under 70% of the increase in ultimate volume of waste discharges. An amount of industrial waste equal to over 20% of the increase in industrial waste production was consigned to public facilities, so that for every incremental pound

TABLE 14

COMPONENTS OF CHANGE IN PRODUCTION OF TWO MAJOR POLLUTANTS 1964 TO 1968

	Change	1964-68
	Millions of Pounds	Annual Rate
Total Increase in BOD	+8110	+6.1%
From people	+ 900	+2.8%
From industrial production	+7210	+7.2%
Sources of Increase in BOD		
Population growth	+ 330	+1.1%
Net expansion of sewer service	+ 570	+1.7%
Production to accommodate population growth	+ 990	+1.2%
Increased per-capita consumption	+6220	+6.3%
Total Increase in Phosphorus	+122.3	+5.9%
Population growth	+ 23.4	+1.1%
Net expansion of sewer service	+ 33.5	+1.7%
Increased per-capita consumption	+ 65.4	+3.3%

of BOD entering public waste handling systems from domestic sources in 1964-68, about one and three quarters additional pounds from manufacturing plants is estimated to have also been accepted.

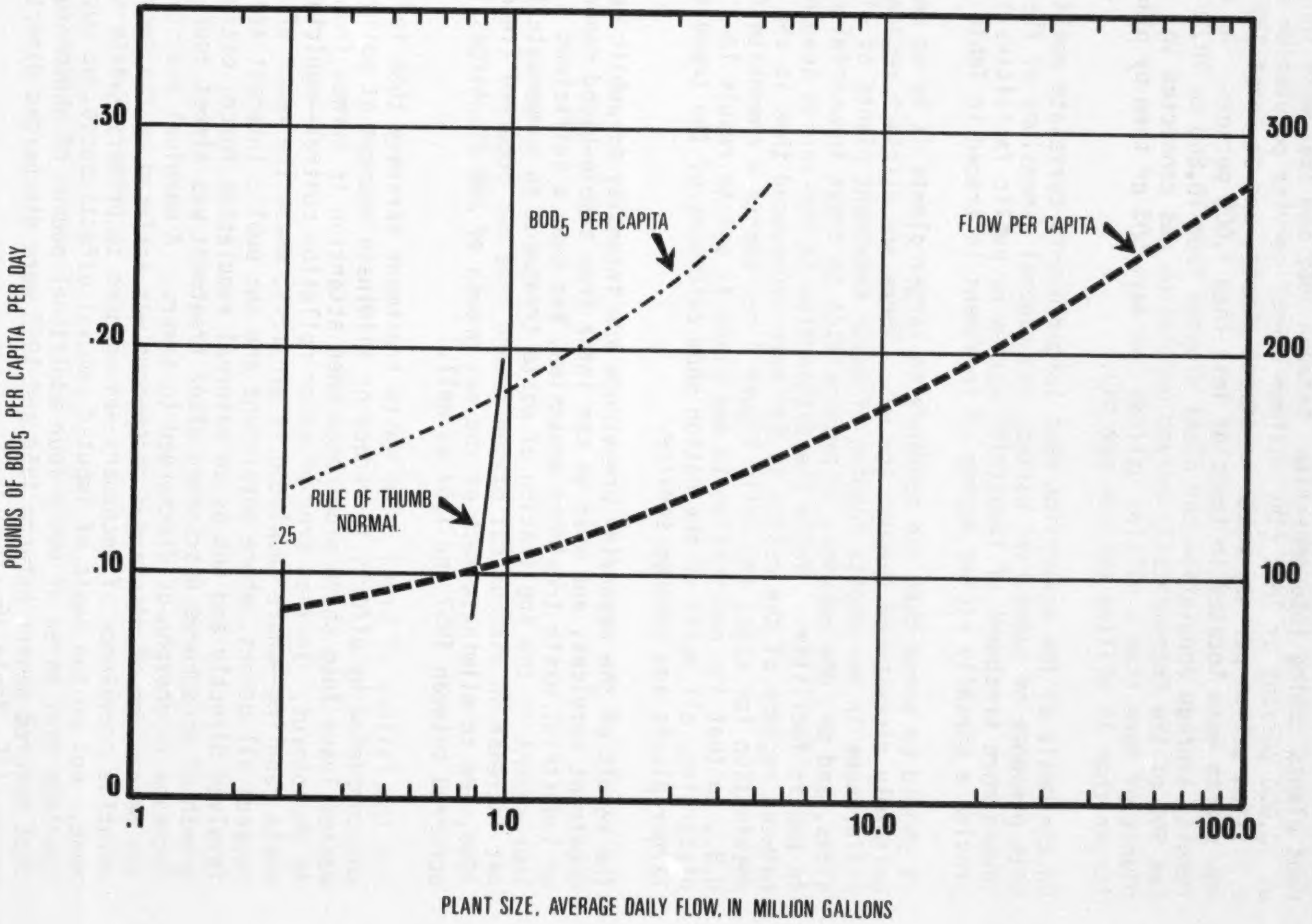
That broader exercise of public authority over the waste discharges of industry unquestionably played a large part in the ability of the economy to reduce total strength of waste discharges. Where an estimated 8 billion additional pounds of BOD were produced in 1968 as compared to 1964, the ultimate strength of wastes discharged was about 2.4 billion pounds less. And though 90% of the incremental wastes were generated by factories, 30% of incremental net removal is estimated to have occurred in public waste treatment plants.

That trend can be very closely traced through the size distribution of the stock of waste treatment plants over time. There is a distinct and well documented relationship (See figure 1) between the size of a waste treatment plant and the per-capita volume and strength of the waste that enters it. Given the fairly homogenous set of social preferences and of product distributions in the U. S., it is unlikely that the relationships trace to different consumption patterns between residents of large and small towns. (Moreover, in the U.S. today the small town with a waste treatment plant is slightly more likely to be a suburb--and thus essentially urban in consumption pattern--than it is a rural place.) The assumption upon which the quantification of publicly treated industrial wastes is based is that increase of per-capita loadings that accompanies an increase in size of plant can be attributed to the discharge of industrial wastes. And while it is true that some rise in hydraulic loadings occurs when increase in size and area add to the probability of infiltration, it should be noted that per-capita area and infiltration probabably tend to decline with population. Even more significant is the fact that increase in waste strength (BOD per-capita) takes place on a far more sharply sloped curve than that for per-capita flow. Given the higher average concentration of industrial wastes, one would expect precisely that sort of relationship between per-capita BOD and water volume in any situation marked by a significant amount of industrial waste discharge.

Some of the major outlines of the recent public investment program for waste treatment works are well understood, but the significance of larger plants is often neglected. Over the last decade and a half there has been a constant reduction in population discharging untreated sewage, a steady rise in the degree of sewage treatment, and a rapid growth of the proportion of the population that maintains sewer service. Less obvious, but equally well documented, is the fact that all of these converging lines of public activity have been accompanied by a steady increase in the size of waste treatment works. That increase in size implies a growing propensity by public agencies to assert control over the treatment of industrial wastes.

RELATIONSHIP OF TREATMENT PLANT SIZE TO PER - CAPITA WASTE LOADING

Figure 1



Increase in average size of waste treatment plant was distributed fairly broadly through the economy, and is not a mere function of population growth. The average population served by a waste treatment plant has been declining as a result of emphasis on facilities for small rural and suburban towns. At least 70% of the new waste treatment plants coming into operation between 1962 and 1968 were in towns of 10,000 persons or less (the maximum normal service population for a million gallon per day waste treatment plant), and at least 28% of the new plants were located in towns of less than 1,000 persons. As a result, average population per plant dropped from 10,860 to 10,350. Yet 90% of the incrementally served population was connected to plants of more than a million gallons per day--50% of them by plants larger than 10 million gallons per day.

On the basis of the assumption that larger plants correlate positively with presence of industrial wastes, the general dimensions of the trend toward more treatment of industrial wastes by public facilities that provide a steadily rising degree of treatment is traced in Table 15.

It should be noted that the tendency to larger plants is by no means uniformly distributed through the U.S. There are distinct regional differences in per-capita loading of waste treatment plants of all sizes, and so, one assumes, in propensities to treat industrial wastes in public facilities. While the distinction in per-capita loading between regions of the nation is far more pronounced than is the distinction for size, and while Figure 1 represents a composite for the U.S., so that its application to any place is apt to result in distortion, all parts of the nation show evidences of the trend to larger plants and broader service.

The result of the expanding prevalence and intensity of public waste treatment services, and what we can infer from sample-based reporting of industrial waste treatment expansion, has been a sufficient improvement in the application of waste treatment to compensate for the net increase in biochemical oxygen demand that has occurred since 1964, and to eliminate much of the net growth of BOD discharges that occurred between 1957 and 1964 as well.

But the failure of broad gauge waste treatment strategy that is unaccompanied by efforts to reduce or eliminate sources of polluting wastes leaps into sharp prominence when attention is turned from BOD to phosphorus. In that area of water pollution control--municipal waste handling--where knowledge is greatest, where the reach of controls exceeds all others, where government and the public interest are involved directly and not as an external regulating force, estimated growth of phosphorus discharged after treatment was almost equal to increase in phosphorus discharged to sewers. A marginal reduction in the percentage of discharged phosphorus was achieved by the increased relative prevalence of secondary--as opposed to primary--waste treatment. But on the basis of imputed removal effectiveness, we must conclude that three of every four additional pounds of phosphorus that entered sewers between 1964 and 1968 were discharged directly to water. (CF. Table 16.)

TABLE 15

NET SHIFT--IN TERMS OF 1962 POPULATION SERVED--IN WASTE TREATMENT PLANT SIZE AND TYPE, 1962-68

Change in Population Served as a Percent of 1962 Sewered Population

Capacity, Million Gallons Per Day	Primary Treatment	Intermediate Treatment & Lagoons	Secondary Treatment	Greater Than Secondary Treatment	TOTAL
Unknown	-1.7	0.5	0.9	-0.2	-0.5
0.5	-0.2	1.3	0.6	-0.1	1.6
0.5 - .999	0.2	0.4	0.4	-1.0	0.9
1.00- 4.99	0.8	0.9	3.6	0.1	5.2
5.00- 9.99	0.6	0.1	2.4	-	3.1
10.00-49.99	1.0	-0.6	4.8	0.3	5.5
50.00-99.99	2.0	0.7	3.2	-0.3	5.6
100.0	0.9	-1.0	4.8	-	4.7
TOTAL	3.6	2.3	20.7	-0.5	26.1

TABLE 16

DISPOSITION OF INCREASES IN TWO MAJOR POLLUTANTS
1964-68

	Change, 1964-68	
	Millions of Pounds	Annual Rate
Disposition of Net Increase in BOD		
Public sewers, populations	+ 900	+2.8%
Public sewers, factory connections	+1570	+8.4%
Separately discharging factories	+5640	+6.9%
Net Discharge of BOD	-2410	-4.3%
From public systems	- 610	-3.3%
From separately discharging factories	-1800	-4.6%
Net Increase in Phosphorus	+122.3	+5.9%

PREVALENCE AND SOURCES OF WATER POLLUTION

Background

The proposed substantial expansion of Federal grants for construction of waste treatment works places the nation at the threshold of an enormous investment program. Current plans call for at least a 50% expansion within the next five years of the value of waste treatment capital put in place during the twentieth century.

Paradoxically, this massive spending program is being undertaken at a time when only about five percent of the sewered population of the nation is not served by waste treatment, and when the degree of waste reduction accomplished by treatment is greater than it has ever been before for the population of the U. S.

There is little question that the money can be spent. Indeed, public comment on the question of funding tends to be directed exclusively to the possibility of deficiencies in the proposed level of spending. And if the public's tendency to question the adequacy of municipal waste treatment funding may be thought to arise more from an awareness of water pollution problems and from urgency with respect to their abatement than from knowledge of the causes of pollution or the status of municipal waste treatment, it is sophisticated analysis of the rate of growth of waste loadings, the shift of industrial waste treatment responsibilities to the public sector, the pressures of upgrading and replacement, and the effects of inflation and technological modification that is responsible for the enlarged investment targets.

There is some question, however, whether the money will be spent effectively. And here the record of the past is not reassuring. The data indicate that cost-effectiveness may be low in the conduct of public waste disposal services.Without significant changes in existing practice, there is slim hope that the rate of environmental improvement will be proportionate to the rate of spending.

Evaluation of programs to abate water pollution on the basis of cost-effectiveness is scarcely possible without first determining the prevalence and causes of water pollution. Prior to the enactment of water quality standards, such determinations were literally impossible, and the definition of a state of pollution was little more than a subjective exercise. While different persons could bring to the exercise varying degrees of knowledge and experience, no one person or group could claim more than self-constituted authority. Amendment of the Federal Water Quality Act in 1966, and the establishment of water quality standards pursuant to the Act, has completely changed that situation. At this time it is possible to take water samples at any point on an interstate water body and, on the basis of a comparison of laboratory determinations with legal definitions specific to that reach of that water body, determine that a state of pollution does or does not exist with respect to a given water quality parameter. Current intra-state standards and, if passed, legislation extending Federal standards to navigable, ground and contiguous zone waters provide almost universal objective evaluation standards. Armed with those legal definitions, it is possible to speak with considerable confidence on the current prevalence of water pollution. The Federal Water Quality Administration* attempted in the summer of 1970, for the first time in the history of the nation, to make just such an assessment for all waters of the nation. Field offices in the nine FWQA Regions estimated the percentage of the stream miles in each of the 233 second order watersheds in the contiguous U. S. (in addition to Alaska, Hawaii, Puerto Rico, Guam, the Virgin Islands, and American Samoa) that could be said to be polluted. Pollution was defined very strictly as a demonstrable and recurrent breach of any of the physical or chemical criteria applying to waterbodies, and not merely as violation of regulatory requirements imposed upon waste dischargers. In addition, for each watershed the assessors estimated the relative weight of eight general classes of activity in causing pollution.

Water pollution may take so many forms that experience and judgement are essential in making determinations. A few years ago, for example, few even considered the possibility that mercury might be a significant pollutant: the element is so scarce and so expensive that its wasting was considered to be highly improbable. There was, then, no known pollution of water by mercury so long as nobody looked for mercury. And any of the natural elements in any of their inconceivably large number of compounds--including living ones--may pollute when present in excessive concentrations. The task of identification is an enormous one, and it is possible that the assessment fails to include the effects of obscure or unexpected pollutants.

Given these difficulties, it is impossible at this time to produce any objective comparative index of pollution which takes account of the multi-dimensional factors which cause pollution. At this point, assesscan be made with fair assurance with respect to one dimension of a multi-dimensional problem. It can be said that water pollution from a specific pollutant does or does not exist for specific places in waterbodies at a given point in time. But there is no universal procedure for relating to the statement of prevalence either time or intensity in a completely general way. It can for example, be said that a river is more polluted or less polluted than it was five years ago if the concern is with adverse effects of the same pollutant. Similarly, comparisons may be made between Stream A and Stream B if the measure of concern is common. But the quantitative measure of the change in the state of pollution if the types of polluting substances are varying is undefined. How, after all, does one weigh a one part per million improvement in the dissolved oxygen concentration of the Delaware River in August against a fifty percent increase in annual production of blue-green algae in Lake Erie? Can one possibly set a five part per million reduction in the fluoride level of Idaho's Portneuf River against a two degree average temperature increase in Maryland's Anacostia River and say that the aggregate water quality of the nation is better or worse?

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* Now the Water Quality Office, Environmental Protection Agency under provisions of Reorganization Plan No. 3, 12-2-70.

Another point deserves to be made about the water quality assessement that is summarized here. It is obviously impossible to provide sufficient data over a sufficient period of time to define in precise, quantitative terms what the quality of the nation's waters may be at any time. Rich as the U. S. is, its economy does not have the resources to conduct such an undertaking. What exist are samples of water quality made at different points and different times. In many cases fixed location testing stations provide recurrent data. In other cases, particular water quality monitoring campaigns have produced background data at a single point, or series of points, on a single occasion or at intervals. On the basis of such data, knowledge of streamflow, and other influences on quality, the assessors have extrapolated judgements. They are, like most scientific generalities, quasi-objective status reports and not actual measurements. The assessors, then, are critical elements of the assessment. The evaluations considered were prepared by men who are, by training and by inclination, attuned to the probability of pollution. The jobs they perform, the experiences they have accummulated, their status, the whole complex of conditions that has given them a particular view of the world, incline them to pessimism. If they err, it is likely to be in the direction of overstatement. These reservations are expressed not to cast doubts on the assessment--it is, after all, a compendium of the judgements of the best qualified professionals--but to indicate the volatile nature of the pollution phenomenon and to provide possible explanations of what may seem to be anomolies.

A Regional Base For Comparisons

The assessment of the prevalence of pollution prepared by Regional Offices finds that almost a third of U. S. stream miles are characteristically polluted. (CF Figure 2.) Half or more of the total stream miles of over 20% of all second order drainage systems* in the U. S. have ben assessed to be polluted. In almost 50% of our watersheds, 20% to 50% of total stream miles are considered to be polluted. Less than 10% of U. S. second order drainage systems were characterized by the assessors to be unpolluted or moderately polluted.

There are distinct regional differences in the prevalence and ostensible causes of pollution. The most general statement of the distinction is that States lying west of the Mississippi River appear to have relatively more miles of polluted stream than do States that lie east of the Mississippi. The fact is entirely consistent with our understanding of the causes of water pollution, the effects of which are magnified by low natural streamflows. Much of the Western U. S. is arid, and that underlying deficiency in the quantity of water makes the task of insuring adequate quality more difficult than in the humid East.

But the distinction between East and West does not adequately characterize the variety of the American water pollution condition. Comparative analysis requires somewhat finer distinctions. For analytical purposes, then, a set of regional groupings are proposed here to distinguish groups of States characterized by similar climatic and hydrologic circumstances, and also by obvious consistencies in economic specialization, demographic trends, and water pollution control strategies. Six broad groupings are proposed, three lying east of the Mississippi River, three west of the Mississippi, (See Figure 3.)

The Pacific Coast States (Washington, Idaho, Oregon, California, and Nevada) combine moderate, humid climates in a thin, densely populated coastal corridor with an arid, sparsely settled eastern plateau that occupies most of the land area. Population growth exceeds that of the other five broad regions; and a distinctly larger portion of the area's population is concentrated in standard metropolitan statistical areas than in the other regions. A very high

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* The nations river systems are geographically classified for purposes of hydrologic description. There are major basins which encompass the waters of the coterminous U. S. These are further subdivided into 233 sub-basins. It is to these that the term "second order" drainage systems apply. They are shown in Figure 4.

Figure 2

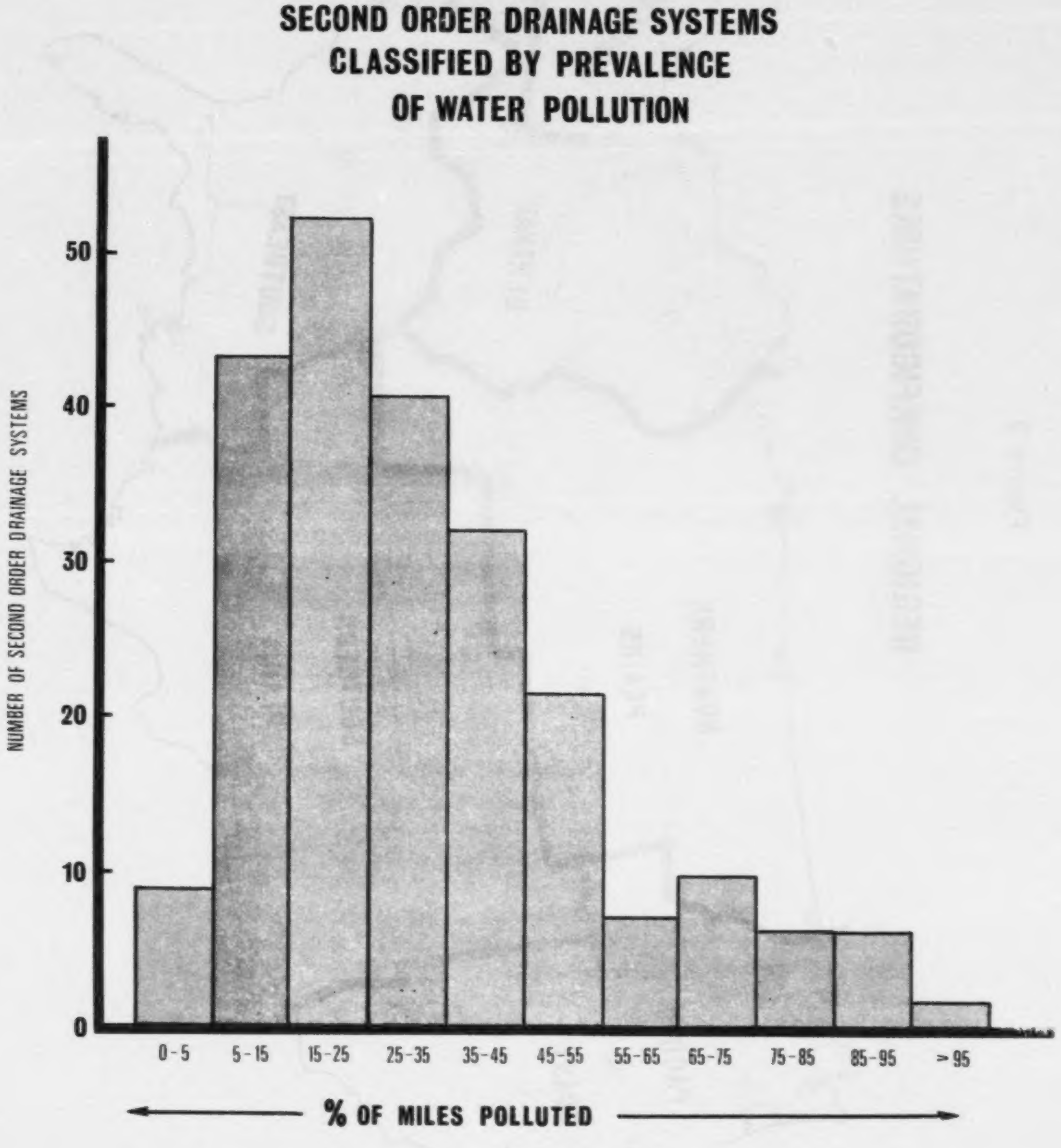
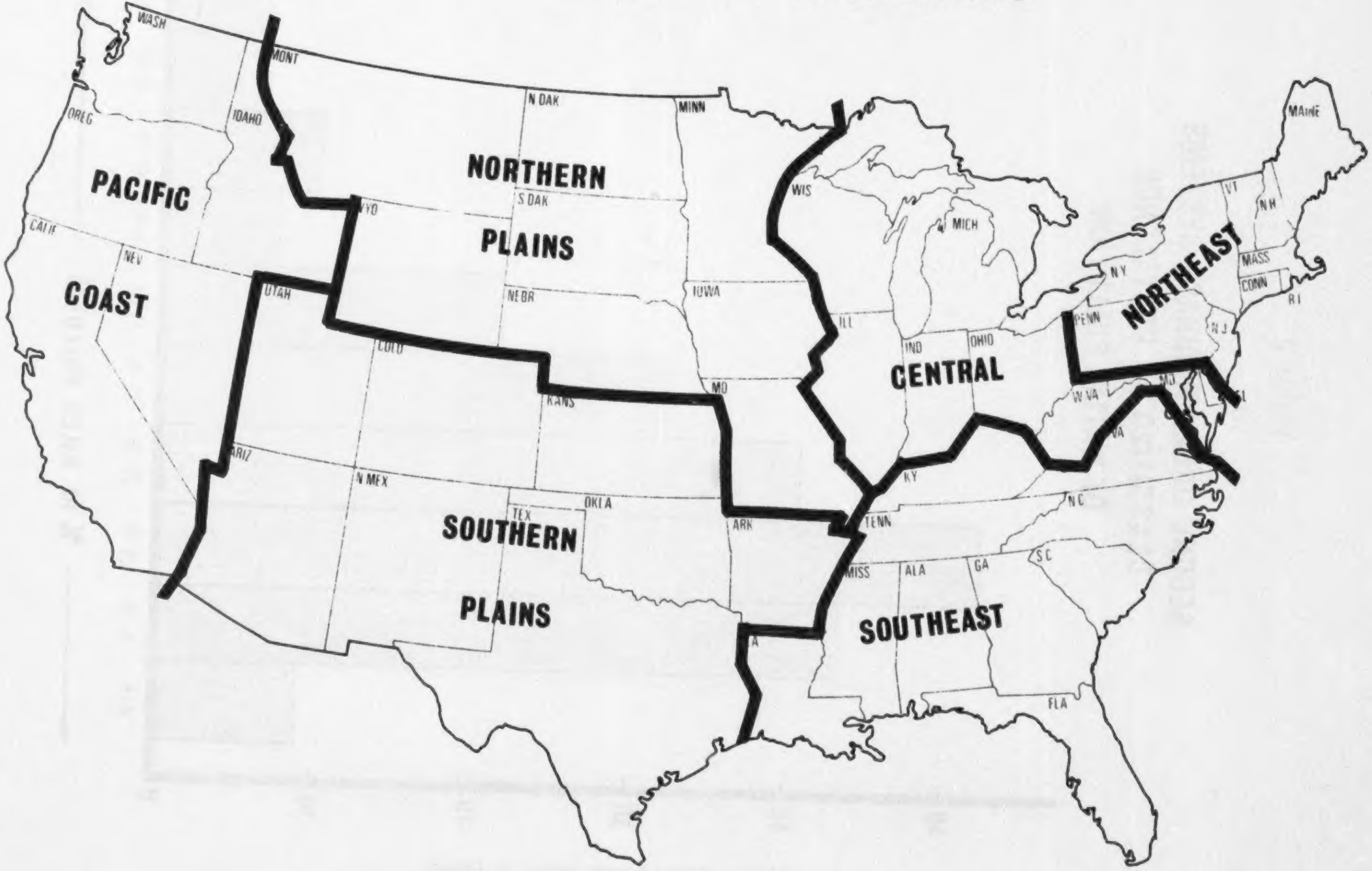

SECOND ORDER DRAINAGE SYSTEMS CLASSIFIED BY PREVALENCE OF WATER POLLUTION
NUMBER OF SECOND ORDER DRAINAGE SYSTEMS
50
40
30
20
10
0
0-5
5-15
15-25
25-35
35-45
45-55
55-65
65-75
75-85
85-95
>95
% OF MILES POLLUTED

Figure 3

REGIONAL CONFIGURATIONS


PACIFIC COAST
NORTHERN PLAINS
SOUTHERN PLAINS
CENTRAL
NORTHEAST
SOUTHEAST
WASH
OREG
CALIF
NEV
IDAHO
MONT
WYO
UTAH
ARIZ
COLO
N MEX
N DAK
S DAK
NEBR
KANS
OKLA
TEX
MINN
IOWA
MO
ARK
WIS
ILL
MICH
IND
OHIO
KY
TENN
MISS
ALA
GA
FLA
S C
N C
VA
W VA
MD
PENN
N Y
N J
CONN
MASS
R I
VT
N H
MAINE

percentage of the total population has sewer connections. Waste treatment is almost universal; but the prevalence of secondary waste treatment is relatively low.

The Northern Plains States (Montana, North Dakota, Minnesota, Wyoming, South Dakota, Nebraska, Iowa, Missouri) constitute the most sparsely populated of the regional groupings; and in spite of the presence of three metropolitan areas having populations well over a million persons each (St. Louis, Kansas City, Minneapolis-St. Paul), very close to half of the total population is non-metropolitan. Population growth is slower than in the other regions, as is the rate of increase in sewering. A substantial portion of the total population was without waste treatment in 1968, at least as compared to the other western regions; though that relative deficiency has been considerably reduced with the completion of the major St. Louis waste treatment plant and the extension of its services to outlying areas. (Over 800,000 persons were discharging raw waste in the St. Louis SMSA in 1968.)

Southern Plains States (Utah, Colorado, Kansas, Arizona, New Mexico, Oklahoma, Arkansas, and Texas) make up the most arid of the six regions, the one with the highest incidence of sewering, and the highest applications of waste treatment. Although recent population growth has occurred at a rate no greater than the nation's, population of the 38 SMSA's has increased at a rate equivalent to that of southeastern SMSA's, and little lower than that of those of the Pacific Coast. A relatively large, but declining, non-metropolitan population component is responsible for the apparent low rate of population growth. Because water is scarce, attention to it is imperative; thus the region not only stands first in incidence of sewering, but leads by a considerable margin in the application of waste treatment at the secondary and higher levels.

The Central States (Wisconsin, Michigan, Illinois, Indiana, Ohio, West Virginia, Maryland-District of Columbia, and Delaware) comprise the most industrialized of the groups of States, are very densely populated compared to the Southeastern or any of the Western groups of States, and are growing in population at just about the same rate as the nation. A large proportion of the metropolitan population is sewered, but a surprisingly small proportion of the non-metropolitan population receives sewer service. Virtually all of the sewered population receives waste treatment; and the incidence of secondary treatment is considerably higher than for the nation as a whole.

The Northeast (New York, Vermont, New Hampshire, Maine, Massachusetts, Connecticut, Rhode Island, Pennsylvania, and New Jersey) is the most populous of the six regions, and the smallest in area. Prevalence of sewering is well above the national average for both metropolitan and non-metropolitan communities; but in spite of the incidence of sewering and its highly concentrated population, application of waste treatment in the Northeast lags the rest of the nation. Almost 12% of the sewered population was without waste treatment in 1968; and those 4.5 million persons constituted 45% of all persons estimated to be discharging untreated sanitary sewage that year (as compared to the region's 24.4% of U. S. population). Relative intensity of treatment, too, is distinctly below the national average, with almost half of the sewered population provided with less than secondary waste treatment, as compared to a little over a third on a national basis.

Southeastern States (Kentucky, Virginia, Tennessee, North Carolina, Mississippi, Alabama, Georgia, South Carolina, Louisiana, and Florida) are the most rural in composition of the six groups of States, but stand second only to the Pacific Coast in rate of population growth. Incidence of sewering is lowest among the six regions, though the rate of expansion of sewer services exceeds that of the other areas east of the Mississippi. The region led all others in relative discharge of untreated sewage in 1968, due in large part to the substantial segment of the sewered population of some of its principal metropolitan areas that was not provided with waste treatment services. (Charleston, S. C. 120,000; Columbia, S. C. 99,000; Jackson, Miss. 130,000; Memphis, Tenn. 522,000; Montgomery, Ala. 164,000; New Orleans, La. 542,000; Savannah, Ga. 124,000; Shreveport, La. 234,000.)* In fact, the metropolitan population without waste treatment of these States exceeded by a considerable amount the combined total for all persons west of the Mississippi plus the central States.

Prevalence of Water Pollution

A substantial portion of American waterways is characterized by FWQA assessors to be persistently polluted. Of 233 second order drainage systems in the forty-eight contiguous States, FWQA could define only 19 in which no greater than 5% of stream miles were continually or recurrently in violation of established physical, chemical, or bacteriological criteria--and 16 of those 19 are found in one area, the region distinguished here as the Southeast. Even with the relatively low prevalence of pollution in the Southeastern U. S., we find that the median and

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* Sewage treatment plants are presently under construction or planned for in these communities.

NATIONAL WATER QUALITY ASSESSMENT:

PREVALENCE OF POLLUTION IN SECOND ORDER DRAINAGE SYSTEMS

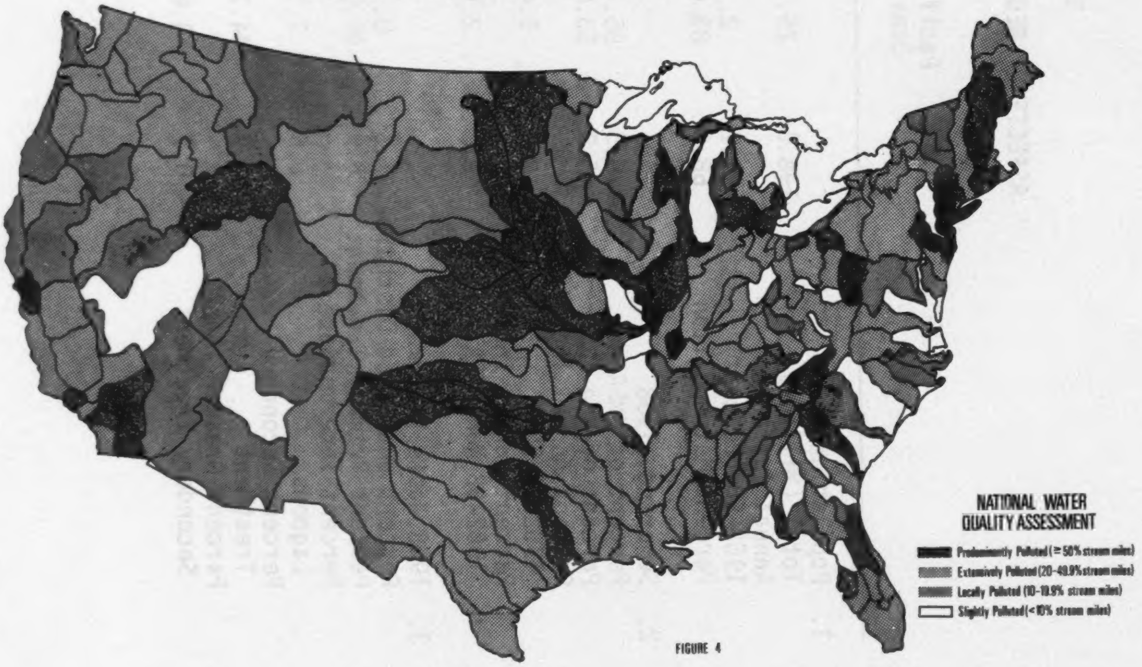
NATIONAL WATER QUALITY ASSESSMENT
Predominantly Polluted (≥ 50% stream miles)
Extensively Polluted (20-49.9% stream miles)
Locally Polluted (10-19.9% stream miles)
Slightly Polluted (< 10% stream miles)

FIGURE 4

TABLE 17

ASPECTS OF REGIONAL SEWAGE SERVICES
1968

	U.S.	Pacific Coast	Northern Plains	Southern Plains	South East	Central	North East
1. Population, 1968							
Total (Millions)	198.0	25.7	14.8	23.5	39.9	45.7	48.3
Annual Increase, 1962-68 (Percent)	1.2	2.1	0.4	1.2	1.4	1.3	0.8
Percent Metropolitan	68.6	83.6	53.4	59.6	46.4	74.8	82.4
2. Sewering, 1968							
Percent of SMSA pop.	79.5	85.1	72.4	84.7	59.9	82.3	82.9
Percent of Non-SMSA	45.9	53.8	48.6	59.8	37.4	36.2	58.7
Percent Annual Increase, 1962-68 SMSA	2.7	5.4	1.1	4.6	2.4	1.8	1.5
Percent Annual Increase, 1962-68 Non-SMSA	2.9	2.5	1.6	3.3	3.3	1.2	4.2
3. 1968 Waste Treatment							
Percent Untreated Discharge	7.3	0.7	13.2	2.0	15.0	1.9	11.9
Percent Primary Treatment	26.6	46.0	22.6	4.6	24.5	22.7	33.5
Percent Intermediate & Lagoons	8.6	7.5	16.7	12.8	7.7	6.0	8.6
Percent Secondary Treatment	56.7	44.7	43.7	80.1	52.4	69.0	45.4
Percent Greater than Secondary Treatment	0.7	1.6	3.7	0.5	0.6	0.2	0.5

modal incidence of pollution for the nation occurs at over 30% of stream miles (cf. Table 18). More than a third of total stream miles are defined to be polluted in every region of the U. S. except the Southeast.

The incidence of pollution, as it is defined by the FWQA national assesment, fits none of the accepted patterns of cause. The conventional wisdom offers no ready explanations for the phenomenon. The fact that the Northeastern States have the highest indicated prevalance of pollution is almost comforting, in that it fits all of the preconceptions. The area is characterized by large and highly concentrated population, massive manufacturing capacity, a relative deficiency in waste treatment. The region should, according to the conventional scenario, have a great number of polluted stream miles. But the Northern Plains States stand second to the Northeast in the average prevalance of pollution, and exceed the Northeast in the relative number of watersheds in the most polluted category, reactions become more than a little uncomfortable. That the sparsely populated Dakotas, almost completely unindustrialized, where every small town has its secondary waste treatment plant, should have relatively more polluted stream miles than New York State is unsettling. And to find that the nation's best water quality--in terms of compliance with water quality standards--is to be found in the region with the lowest incidence of waste treatment does additional violence to any complacency about the direction of existing pollution abatement programs.

Not even the most ancient of our conceptions of sources of water quality degradation, deficiency of streamflow, holds up entirely. While eastern streams, in total, are judged to be less extensively polluted than western streams, the better showing traces entirely to the waters of the Southeastern States. Pacific Coast States provide a consistently better record of compliance with water quality standards than either the Central or the Northeastern States; and even the most arid of the six regions, the Southern Plains, compares quite favorably with the Northeast and not unfavorably with the Central States.

We are left, then, with only a single certainty. A very large portion of all U. S. waters consistently demonstrates quality characteristics that violate established criteria. These violations occur in densely populated and sparsely populated areas, in humid and arid climates, in industrialized, in agricultural, and in forested regions, and apparently without reference to either the prevalance or the intensity of waste treatment. The lack of a pattern makes it impossible to judge whether conditions are improving or deteriorating; but the consistency of the pattern of pollution suggests that there may be inefficiencies in current approaches to pollution abatement.

TABLE 18
GENERALIZED PREVALENCE OF POLLUTION, 1970

Region	Percent of Stream Miles Polluted	Percent of Watersheds In Pollution Status			
		Predominantly Polluted 1/	Extensively Polluted 2/	Locally Polluted 3/	Slightly Polluted 4/
Pacific Coast	33.9	14.8	59.3	22.2	3.7
Northern Plains	40.0	37.5	33.3	25.0	4.2
Southern Plains	38.8	27.3	51.5	18.2	6.1
Southeast	23.3	14.3	41.1	16.1	28.6
Central	36.6	23.2	51.8	21.4	3.6
Northeast	43.9	36.1	55.6	5.6	2.8
E. of Mississippi R.	31.6	23.0	48.7	15.5	12.8
W. of Mississippi R.	35.5	24.1	47.1	20.7	4.6
U. S.	32.6	23.7	48.5	17.7	9.9

1/ Predominantly Polluted : $\geq$ - 50% of Stream Miles Polluted

2/ Extensively Polluted: 20 - 49.9% of Stream Miles Polluted

3/ Locally Polluted: 10 - 19.9% of Stream Miles Polluted

4/ Slightly Polluted: < 10% of Stream Miles Polluted

Causes of Water Pollution

The apparently erratic geographic distribution of water pollution may be explained in part by a review of apparent causes. The national assessment of the prevalence of water pollution included an evaluation for each second order watershed of the indicated causes of pollution, in terms of relative weight.

Causes of pollution were classified according to their association with categories of human activity. Natural causes of poor water quality were not considered, on the basis that water quality standards are, at least in theory, developed in terms of water uses that are possible within the framework of natural conditions. Recognized sources of pollution for the assessment were eight:

1) Municipal Wastes include all wastes that are collected and transmitted through community systems of sanitary sewers. Both commercial and domestic sanitary wastes, and the wastes discharged by manufacturing plants to public sewer systems, fall into the category.

2) Other Urban Wastes include the waterborne residues of urban activity that do not routinely enter the system of sanitary sewers. Direct runoff from urban areas, overflows and bypasses of waste treatment plants caused by combined storm and sanitary sewers, and the unassimilated drainage of septic tanks comprise the major elements of the category.

3) Industrial Wastes include the separately discharged wastes of manufacturing. Both process waters and manufacturers' cooling waters fall under this heading.

4) Electrical generating was defined to include the discharge of heated cooling waters of thermal power generating stations, the presence of radioactivity from nuclear fueled power plants, and the particulate fallout and acidity associated with fossil fueled power plants. In several watersheds, however, the disruption of the natural hyrologic regimen associated with generation of hydroelectric power was included by assessors under this category rather than the general category of "other" which was intended to include all water management activities.

5) Agriculture, as a source of water pollution, includes the effects of runoff on siltation of streams, organic and nutrient loadings originating with livestock, concentrations of pesticides and herbicides from the runoff of agricultural lands, and salinity that occurs with leaching and evapotranspiration in the irrigation process.

6) Mining's effects on water quality include siltation from scarred lands, acid drainage from reaction of water with exposed mineral seams, and pumping of brine deposits.

7) Spills, which receive a great deal of attention because of their often catastrophic nature, include the deposit in water of any polluting or toxic material as the result of accident.

8) Other sources of water pollution are, obviously, unlimited in concept, since they include any human event or activity not considered under one of the other seven categories of polluting activity. In practice, however, the "other" category resolves into three principal classes: water management in the highly regulated streams of the west, the promotion of sedimentation by construction, and the effects of transportation--principally navigation--including stream dredging.

The use of the eight categories of polluting practices is valuable for analytical purposes and for program formulation, but the real world distinction among pollution's causes are not nearly so distinct as the employment of the specific categories would imply. In practice, water pollution can rarely be traced to a single cause. In most cases, all eight forms of activity occur in the same watershed--and several of them may be found at approximately the same stream point. Distinguishing their relative impact, then, is very largely a matter of judgment and study.

The indicated causes of pollution, it must be stressed, do not constitute as reliable an assessment as that of the prevalence of pollution. Judgment as to the occurrence or absence of pollution requires extrapolation between measured points in space and in time. In the case of causes, it requires a rather fine distinction among simultaneous occurrences, a weighting of the relative significance of inter-related conditions.

As in the case of the prevalence of pollution, this study's procedure includes no effort to revalue the judgments of the assessors. All data have been accepted as they were given, on the basis that the experienced judgment of the men on the scene must in most cases be better than that of the analyst removed from the event.

On the other hand, it must be recognized that there is something that is essentially specious about any effort to quantify the relative contribution to water pollution of various activities. The distinctions are simply too fine and interdependent for accuracy. For this reason, the analytical method has attempted to further separate the various influences on water quality into distinguishable prime causes and all other.

TABLE 19

PRIME CAUSES OF
STREAM POLLUTION, ALL
SECOND ORDER
WATERSHEDS

Prime Causes, In Descending Rank	Percent of Stream Pollution Attributed to Prime Causes						
	U. S.	Pacific Coast	Northern Plains	Southern Plains	Southeast	Central	Northeast
Industrial Wastes	23.7	12.7	21.0	9.2	34.7	21.5	33.5
Municipal	21.8	13.0	15.6	14.2	21.2	28.5	27.1
Agriculture	11.2	19.1	28.8	27.6	1.3	5.8	0.5
Other	3.7	11.8	0.6	16.6	1.7	0.4	-
Mining	2.8	2.4	2.6	12.6	0.3	4.9	2.6
Other Urban Wastes	0.9	-	-	0.1	0.7	1.9	1.3
Power Generation	0.4	1.5	-	-	0.6	0.6	0.1
Spills	0.1	-	-	-	-	0.2	-
Total Prime Causes	64.6	60.5	68.6	70.3	60.5	63.8	65.1

The selection principle was simple enough. In every watershed the assessors indicated that from five to eight of the categories of activity added to pollution of water. The analytical procedure was to select the smallest number of those causes that could be added together to account for at least 50% of the indicated pollution. These were then considered to be prime causes for that watershed. There is no difference in the aggregate between the categories of activity that are considered to be prime causes of pollution and those that are considered to be contributory causes. The distinction was made separately for each second order watershed. In most instances, one or two causes were thought to account for half or more of the polluting effects. For all watersheds, the mean number of prime causes was 1.8, and the proportion of pollution attributable to them was greater than 65%--indicating that, in general, the major indicated cause of pollution in any instance is substantially more significant than other causes. Comparative significance of prime causes was assigned, within regions as well as for the nation as a whole, in terms of index numbers based on stream miles and degree of pollution. ([percent prevalence of pollution multiplied by stream miles multiplied by percent pollution attributed to a prime cause] divided by [the sum of percent prevalence of pollution multiplied by stream miles] = percent of pollution attributed to a prime cause.) Again, the procedure is by no means precise, but by limiting the analysis to prime causes, it is hoped that uncertainty attributal to background conditions is reduced, so that we distinguish the more obvious (and thus, hopefully, better founded) portions of the assessment.

The array of pollution sources reveals sharp differences in their impacts. Municipal and industrial wastes are evaluated to be the majority sources of pollution (cf. Table 19), and to be of approximately equal impact on a national basis. Industrial wastes emerge as the principal source of pollution in two regions, municipal wastes in one. In total, industrial wastes are indicated to be a fractionally greater cause of pollution; but the values are so impressionistic that the difference can scarcely be considered real,much less significant. The parity accorded the two kinds of wastes by the assessors is unexpected, in view of greater quantity of industrial waste and the slightly higher estimated treatment efficiency in the public sector. (Surprising, too, is the fact that the one region in which municipal wastes are considered to be the leading cause of violations of stream criteria is the Central States, the most industrialized of the six regions.) One must presume that the relative importance assumed by municipal wastes strongly reflects frequent violation of bacteriological standards and increased fertility of water attributed to phosphorus discharges. Other possible explanations include the diffusion of municipal waste sources--significant to an assesment based on prevalence rather than intensity of pollution, concentration on traditional sanitary interests, and difficulty in measuring effects of some of the more obscure industrial wastes.

Agriculture, standing third nationally as a source of water pollution, is considered to be the leading cause in each of the three western regions--and by a distinct margin over either municipal or industrial wastes in each case.

Mining and "other" sources of pollution each receive some consideration as prime sources of water pollution, with mining's contributory effect noted in all six regions, "other" sources largely restricted to the Pacific Coast and Southern Plains.

"Other urban wastes," power generation, and spills tended to be relegated by the assessors to the category of secondary or subsidiary sources of pollution. Their combined contribution, as prime sources, amounts to less than 1.5% of the total; and each tends to occur only in particular, scattered instances. While this might be expected in the case of spills, which occur mainly as accident, and so only in an actuarial or probabilistic sense in any listing of causes of recurrent pollution, one receives the distinct impression that the polluting effects of power generation and of unsewered urban drainage may well have been overlooked in many instances as a result of concentration on the obvious. Certainly the technical literature is full of examples of adverse water quality impacts from these sources.

The full range of differences between east and west becomes sharply evident when attention is shifted to the comparative contribution of the several categories of activities to stream pollution under varying degrees of prevalence. (cf. Table 20).

While the polluting influence of agriculture tends to remain constant over the various degree of pollution categories in the west, and the relative influence of municipal wastes declines with increased prevalence of pollution, the exact opposite is true in the east. At least two explanations come readily to mind. On the one hand, there is a distinctly lower incidence of waste treatment east of the Mississippi, together with a much larger total population. So it is entirely conceivable that some of the polluting effects of agriculture are masked by the overriding influence of municipal (and industrial) wastes. On the other hand, western agriculture is vastly different in the aggregate from that of the east. It is more extensive, characterized by larger land units, row crops, and highly mechanized operations. It tends to be more wasteful in its use of soils in order to make fuller use of its larger capital inputs. (Thus, for example, a study of diffusion of municipal waste sources--significant to an assesment based on prevalence rather than intensity of pollution, concentration on traditional sanitary interests, and difficulty in measuring effects of some of the more obscure industrial wastes.

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TABLE 20
PRIME CAUSES OF STREAM POLLUTION, BY EXTENT OF POLLUTION

Prime Causes and (Rank)		Percent of Pollution Attributed to Prime Causes			
	All Streams	Predominantly Polluted	Extensively Polluted	Locally Polluted	Slightly polluted
Industrial Wastes (1)	23.7	24.9	24.0	14.9	20.8
East of Miss. R. (1)	28.9	31.0	28.3	19.6	18.2
West of Miss. R. (2)	14.6	14.8	15.7	8.4	12.4
Municipal Wastes (2)	21.8	23.2	19.6	23.7	27.2
East of Miss. R. (2)	26.0	26.5	25.0	29.4	34.5
West of Miss. R. (3)	14.4	17.8	9.9	15.7	34.3
Agriculture (3)	11.2	10.5	110.8	18.9	5.5
East of Miss. R. (4)	2.9	1.4	3.0	14.0	5.4
West of Miss. R. (1)	25.8	25.5	26.5	25.7	19.1
Other (4)	3.7	3.1	4.6	3.2	0.4
East of Miss. R. (7)	0.6	-	1.2	1.3	-
West of Miss. R. (4)	9.3	8.2	11.4	5.7	4.8
Mining (5)	2.8	3.0	2.3	2.5	5.8
East of Miss. R. (3)	2.9	3.9	2.2	-	7.1
West of Miss. R. (5)	2.5	1.5	3.0	6.0	9.5
Other Urban Wastes (6)	0.9	1.0	0.9	0.2	-
East of Miss. R. (5)	1.4	1.6	1.4	-	-
West of Miss. R. (7)	-	-	-	0.4	-
Power Generation (7)	0.4	0.3	0.6	-	0.9
East of Miss. R. (6)	0.5	0.6	0.4	-	1.2
West of Miss. R. (6)	0.4	-	0.9	-	-
Spills (8)	0.1	-	0.1	-	-
East of Miss. R. (8)	0.1	-	0.2	-	-
West of Miss. R. (8)	-	-	-	-	-

sedimentation in the Palouse River Basin of Washington and Idaho found, over a period of years, a much tighter correlation of silt loadings to fertilizer sales than to streamflow or precipitation. As farmers found it cheaper to synthesize new soils with chemical fertilizers than to preserve them, farming practices apparently altered in a fashion that promoted erosion.) There is relatively less forest and pasture cover to hold western agricultural land. A large portion of the cultivation of the west is an irrigated agriculture, in which water represents a planned resource input, increasing opportunities for hydraulic displacement of soils, depleting streams, and enhancing salinity. Western agricultural practices relating to livestock, too, are inherently more pollutional, in that feeding operations that concentrate large numbers of animals in a limited space have become an integral part of the industry. Such feed lots produce point sources of wastes that, under some conditions, equal the polluting effects of major metropolitan areas.

Other obvious distinctions relate to the influence of mining and "other urban wastes." Mining, as a prime source of pollution in the east, seems to exercise some of its effects in the watersheds where pollution is most prevalent, as do "other urban wastes." The reverse is true in the west, where mining would seem to be a source of localized pockets of pollution rather than a basin-wide influence. The differences probably trace to the character of the industry. Eastern coal mining is an essential part of the industrial base, with population and manufacturing centers located near the coal fields. The petroleum and heavy metals extraction of the west tend to be isolated; and the nature of the mining process and of soils tends to produce environmental impacts that are less extensive as well as less apt to be reinforced by other activities. In the category of "other urban wastes," precipitation patterns and a smaller scale of metropolitan units may limit relative pollution effects in the west, as may the lesser incidence of combined storm and sanitary sewers.

Perhaps the most dramatic of the differences between east and west is hidden in the undifferentiated category "other." The role of water management in arid areas is seldom considered in connection with water pollution; but the modification of streamflows that can vary from complete interruption of flow during the storage period to flooding rushes when storage reservoirs are filled, when the irrigation season is underway, or with peak generation of hydroelectricity, creates an environment that is inimical to maintenance of water quality standards. In the more extensively polluted watersheds of the Pacific Coast and the Southern Plains, the category is given a weight that is roughly equal to that of municipal wastes as a cause of pollution.

The value of the assessment in resource allocation decisions as discussed next is significant. Because this was the first such assessment attempted, there may well be reservations as to the precision of its results: but it does provide a new and enlightening view of the entire water pollution picture. Future activities in this area will be designed to reduce the imprecision and reservations to enhance the utility of this form of assessment.

Pollution Causes and Resource Allocation

Having established, in an admittedly subjective manner, the relative significance of major categories of polluting activities, the way is open to consider current resource allocation procedures that affect water pollution control. The task is by no means an easy one. Reliable data are simply not available for most of the eight kinds of activities known to cause water pollution, so that one is forced to make do with order of magnitude statements.

Industrial wastes, which account for almost 80% of sewered oxygen demand and for 34% of estimated stream pollution, have been the source of about half a billion dollars a year of investment and several hundreds of millions a year of operating costs over the last three years. Current targets call for investment to be increased to over $600 million a year.

Municipal wastes, which account for a little over 20% of sewered oxygen demand and are presumed to be the principal source of nutrient phosphorus, are estimated to be responsible for a third of all stream pollution. Investments, about a billion dollars a year over the last three years, will step up significantly as a result of increased Federal financial assistance. Operating costs, that currently approach $300 million a year, should come close to half a billion by the middle of the current decade. A very minor part of the added financial burden will be directed toward alleviating the nutrient problem, believed to be the principal mechanism by which sanitary sewage causes water pollution today.

Agriculture, estimated to cause almost 20% of all stream pollution, makes almost no direct investment for pollution control purposes. Costs of remedial procedures--including erosion control, limitation of use of some pesticides, locational practices for feed lots and dairies--may amount to several tens of millions of dollars each year, with the benefits experienced in such areas as nuisance alleviation, increased productivity, and land resettlement alternatives as much as in water pollution control.

Other activities producing pollution--water management practices, construction, navigation, and recreation--are estimated to cause slightly more than 6% of stream pollution, most of it west of the Mississippi. Again, control measures can amount to no more than tens of millions, occurring principally in the form of higher construction costs.

Mining is estimated to account for about 5% of stream pollution, concentrated largely in the Appalachian coal mining region. The petroleum industry has indicated that its expenditures for pollution control consequences of production exceed $100 million a year. While no estimates of costs have been presented for other mining sectors, it is considered improbable that their total would approach half of that claimed for petroleum extraction.

Other urban wastes, estimated to account for a little over 1% of stream pollution, are approached almost entirely as a function of the system of storm and sanitary sewers that currently sustains an annual investment of about $600 million. It is uncertain to what extent the sewering program serves to alleviate water pollution due to urban drainage--indeed, there is some concern that the net effect of such programs is negative with respect to water quality.

Power generation is estimated to be directly responsible for less than 1% of stream pollution. Current investment in cooling water recycling facilities by the steam power industry is in the area of $200 million a year. Air pollution control investments are approximately equal; and these have collateral water pollution control benefits in some cases, a function of reduction in fallout of particulate matter.

Spills are accorded responsibility for almost no recurrent water pollution, though intermittent spill damages have proved in some cases to be locally catastrophic. It is impossible to estimate costs of spill control measures, both because procedures are undefined in some cases, and because controls tend to be an inextricable part of the--largely industrial--production system that results in spills.

It is a crude sort of balance sheet drawn up here, but it does indicate that there may be distortion in the way resources are allocated for water pollution control. Sewered wastes have been estimated in these pages to account for more than two-thirds of stream pollution. They also receive almost all of the accountable expenditures for pollution control--very close to $3 billion a year--with the amount certain to rise sharply over the next few years. Other kinds of polluting activities receive about $300 million of accountable expenditures by the petroleum extraction and steam power generating industries, and possibly several tens of millions from a variety of other interests. Polluting effects, estimated to be twice as great for sewered wastes as for other kinds of polluting activities, are countered by an allocation process that devotes almost ten times as much for sewered wastes as for the other procedures that may cause water pollution.

On the other hand, one cannot make the off-hand judgment that control of sewered wastes is overfunded relative to other categories of pollution control. There is so tenuous a grasp of control possibilities for unsewered pollutants that we do not know what control measures are possible in many cases, much less what is necessary or practical. Relative prices, then, will have to be taken into account, together with pollution reduction potential in making determinations of the aggregate effectiveness of water pollution control allocations. Current relationships could conceivably be optimal.

The fact that we do not know the optimum relationships is enough, however, to indicate that the nation is devoting an insufficient amount of attention to the relative seriousness of pollution resulting from sources other than sewered wastes.

DISECONOMIES IN PUBLIC WASTE MANAGEMENT ACTIVITIES

Although the preceding discussion suggests the possibility that the allocation processes that assign resources to remedy water pollution are flawed by excessive concentration on sewered wastes, the fact is currently impossible to determine. So exclusive has been the thrust of water pollution control in the one direction, that there is only general and impressionistic basis for suggesting that other pollution-producing economic activities are neglected. No basis for comparing any distribution of resources with a theoretical optimum at any level of national expenditure can be developed as long as determinations have not been made regarding the cost, desirability and degree of control for non-sewered pollution sources. On the other hand, it is possible to determine generally what economic loss, on a national basis, ensues from suboptimal allocation of resources within the category of sewered wastes and treatment for those wastes. (That is not to say that definition of diseconomies offers any prospect of reducing their dimensions. For the most part, the economic losses stem either from uncertainty or from institutional constructs so strongly rooted that their elimination might involve a higher cost than that of the diseconomy they create.)

From an economic standpoint, though perhaps not from a regulatory one, there are continuous and substantial losses that ensue from two sources; promotion of sewering, and overdesign of facilities, may be viewed as institutionalized allocational impediments to totally cost effective investment.

Promotion of Sewering

Diseconomies that stem from unnecessarily accelerated sewer connections are significant. While a direct measurement of their amount would require costly and extensive surveys, their general dimensions can be determined by reference to relative growth of U.S. population and of sewered population. (cf Table 21.)

Bureau of Census estimates indicate that between 1962 and 1968 national population increased by roughly 14 million persons. Estimates of sewered population compiled by State health and water pollution control agencies indicate that in the same period sewered population increased some 20 million persons, almost half again as much in gross numbers, more than twice as fast in terms of rate of increase.

TABLE 21
RELATIVE GROWTH OF POPULATION AND SEWER SERVICE
1962-1968

Region	1962 Population, 1000's Total	1962 Population, 1000's Sewered	Percent Sewered	1968 Population, 1000's Total	1968 Population, 1000's Sewered	Percent Sewered	Annual Rate of Change
Pacific Coast, Metro	18,246	13,333	73.1	21,519	18,322	85.1	2.8% 5.4%
Other	4,547	1,959	43.1	4,217	2,269	53.8	-1.1% 2.5%
N. Plains, Metro	7,343	5,361	73.0	7,903	5,720	72.4	1.2% 1.1%
Other	7,092	3,038	42.8	6,879	3,342	48.6	-0.4% 1.6%
S. Plains, Metro	12,191	9,062	74.3	14,016	11,877	84.7	2.4% 4.6%
Other	9,784	4,679	47.8	9,506	5,682	59.8	-0.5% 3.3%
S. East, Metro	15,986	9,596	60.0	18,505	11,080	59.9	2.5% 2.4%
Other	20,665	6,565	31.8	21,418	8,020	37.4	0.6% 3.3%
Central, Metro	31,190	24,905	79.9	34.187	28,132	82.3	1.5% 1.8%
Other	11,218	3,857	34.4	11,503	4,162	36.2	0.4% 1.2%
N. East, Metro	37,373	30,180	80.8	39,743	32,934	82.9	1.0% 1.5%
Other	8,538	3,950	46.3	8,605	5,051	58.7	0.1% 4.2%
TOTAL Metro	122,328	92,437	75.6	135,873	108,065	79.5	1.8% 2.7%
TOTAL Other	61,845	24,049	38.9	62,127	28,526	45.9	0.1% 2.9%
U.S.	184,173	116,486	63.3	198,000	136,591	69.0	1.2% 2.7%

While there is no direct relationship between rate of population growth and a desirable rate of sewer connections, since local population density and soil conditions are the basic factors that dictate use of sewers rather than individual septic tank systems, there should be some underlying correspondence of the two rates. But both the higher over all rate of growth of sewering and the disproportionate growth of sewering in rural and non-metropolitan urban areas lead to the inference that sewering is being extended far beyond any circumstances dictated by physical need. At a time when the non-metropolitan population of the U.S. increased by some 300,000 persons, sewer service to the population component added some 4.5 million persons; and even in the areas west of the Mississippi, where non-metropolitan population was declining, non-metropolitan sewered population increased by some 1.6 million.

The critical point to be made here is that sewering, considered in an environmental sense, is one of the prices paid for our urban condition. To the point that the assimilative capacity of soils is not exceeded, it is infinitely preferable to use ground disposal procedures. They have the great virtue of recycling the materials so disposed, both by replenishing water tables and by converting and utilizing organic and inorganic waste matter in natural life processes of decay and growth. Their secondary merit is more germane to this discussion. Water reaching watercourses after passage through the filtering and decomposition processes afforded by soil is far purer--provided that soil loading rates are not exceeded--than any waste treatment process short of distillation could make them. The effect of sewering is to transfer conditions of soil pollution or groundwater pollution to surface waters. To make that transfer where sewage loadings are not so great as to threaten soil or groundwater pollution is to create surface water pollution.

Yet there is a tendency to regard sewering as a progressive and sanitary process in all cases, and as a general rule to discourage and impede the alternative of ground disposal. Many State health departments actively promote sewer installations, as do Federal programs.

Sewering beyond the level dictated by environmental considerations, then, must be conceded to be a polluting influence, with the influence exercised in surface waters. That pollutional impact is reinforced by the fact that local resources diverted to sewer installation may be denied to necessary waste treatment works. The situation is a universal one, but its effects are most noticeable in the Northeast.

TABLE 22
CALCULATED INCREASE IN SANITARY WASTE DISCHARGE DIRECTLY ATTRIBUTABLE TO ACCELERATED SEWERING - NORTHEASTERN STATES, 1962-1968

	Thousand Population Equivalents of BOD	
	Metropolitan	Other
1962 Sewered Population	30,179.6	3950.3
Mean Waste Reduction*	.697	.674
Daily Waste Discharge, 1962	9,144.4	1287.8
'Normal' Sewering, 1962-68	1841.0	23.7
Additional Sewering, 1962-68	913.3	1076.9
Mean 1968 Waste Reduction*	.679	.621
Daily Waste Discharge, 1968	10,571.8	1914.3
Increase, 1962-68	1,427.4	626.5
Directly Attributable to Accelerated Sewering	293.2	408.1

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* $\frac{.35 P_p + .85 P_s}{P}$

where P_p = sewered population with primary treatment
P_s = sewered population with secondary treatment
P = total sewered population

In that region, where untreated sanitary waste discharges are massively concentrated, water pollution abatement has been retarded significantly by the allocation of resources to the sewering of rural communities. The effects--not adjusted for overloading of waste treatment plants or public treatment of industrial wastes--are demonstrated in Table 22, which depicts a significant increase in oxygen demand of both total sanitary wasteload and of discharged sanitary wastes occurring between 1962 and 1968 as a result of a substantial sewered population increment beyond that indicated by population growth alone, and a related decline in the intensity of waste treatment.

Over-capitalization of Treatment Works

A recent newspaper story carried a two column photograph with the following caption:

> Control Panel Inspected
>
> . . . inspects a control panel at the $2 million . . . sewage plant expected to go into operation . . . by the end of the year. The plant, under construction since a year ago last summer, is expected to handle three million gallons of waste a day. It is being built simultaneously with a $1 million expansion of the . . . plant. The facilities have been designed to serve a population of 100,000, four times the present . . . population.

One senses in the intent face of the inspecting technician who has been photographed a certain efficient satisfaction with the bank of controls and recording instruments; and the flat, no-nonsense journalistic prose of the caption has only a faint hint of civic pride in the new facilities. There is no indication that anyone is, or should be, disturbed at the thought of spending $3 million to construct facilities that, when completed, will be 75% unused, at financing the unutilized capacity at about 6% a year, or at assuming excess annual operating costs of approximately $15,000 per million gallons a day of sewage throughput. These things are, apparently, taken for granted. And the situation cited is by no means unique--more than 7% of the municipal waste treatment plants in the U.S. are scaled to accommodate four or more times their current loading. (Such plants account, however, for only 4.4% of gross capacity, due to the tendency for over-design to occur principally with smaller plants in smaller communities.) (cf Table 23.)

The conventional explanation for installing multiples of currently needed capacity is that they are intended to provide for future growth. And in the case cited, the community is part of an SMSA that has experienced extraordinary population growth since World War II, thus a considerable amount of spare capacity might be a good idea. However--if the city should continue to grow in population at the very high rate (2.8% a year) experienced from 1940 through 1970, it would take 50 years to fully utilize its current capacity. Should its population growth expand to that of the total SMSA over the last 20 years (3.8% a year), it would be using up its excess in only 37.5 years. And if population expansion should really skyrocket to the over all rate of the county, in which it is located (5% a year), only 28.5 years would be required to get 100% utilization of a set of facilities built to serve over a 'normal' operating span of 25 years.

In defense of the communities like the one cited, it should be noted that overdesign of waste treatment plants is not generally considered to be an abuse. To the contrary, standard design practice calls for the construction of facilities that are scaled to some "prudent" multiple of the existing loading rate, both to provide against loading surges and to have them available for larger future needs. The procedure makes such obvious good sense that there should be no need to call attention to it.

But there is room for disquiet when one takes into account the fact that fully a quarter of metropolitan area waste treatment plant capacity is less than half utilized, and that for non-metropolitan communities, over thirty percent of total waste treatment plant capacity is utilized at less than half of design rating. When one excludes the one sixth of all waste treatment plants that are overloaded, the mean utilization rate for publicly operated plants in the U.S. is found to be just under 63%--almost two-fifths of the total capacity of plants of every vintage, then, is simply unused. Worse, in terms of aggregated probabilities, much of it will never be used. The formal useful life of a waste treatment plant is 25 years. At the rate of population growth that applied during the 1950's only the fastest growing classes of communities could make full use of the capacity of a plant designed to serve twice its initial loading (cf. Figure 5). The rate of population growth has been declining without interruption since 1957; and during the 1960's it sank to 70% of the rate for the previous decade. Under those circumstances, one would anticipate that the margin of excess capacity would decline. Instead, it has been rising.

RELATIVE POPULATION GROWTH EXPECTATIONS BY CLASS OF COMMUNITY BASED ON 1950-60

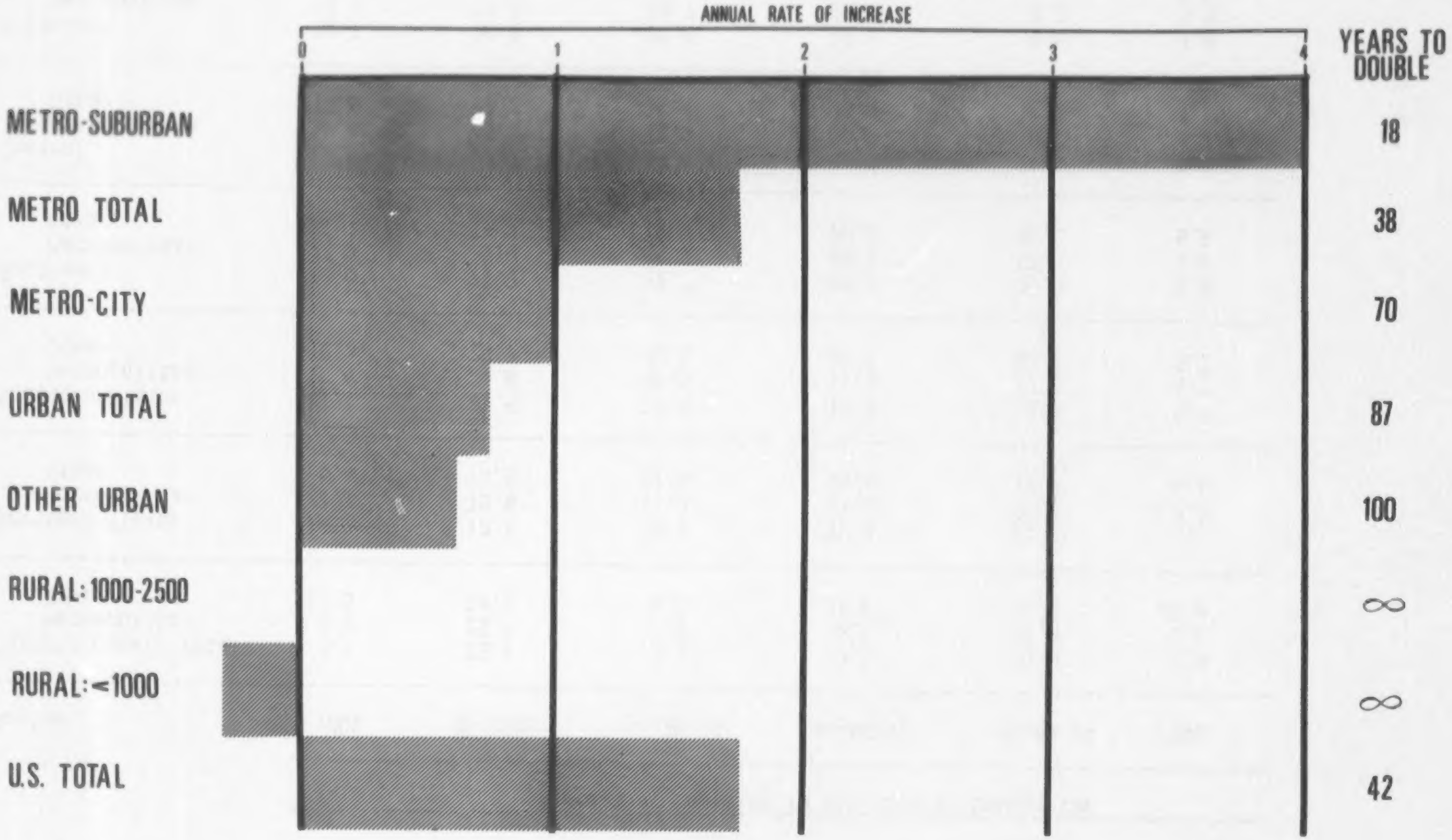

FIGURE 5

TABLE 23
REGIONAL DISTRIBUTION OF UTILIZATION RATES
1968

Region	Percent of Capacity in Utilization Categories					
	>100%	80-100%	67-79.9%	50-66.9%	25-49.9%	<25%
Pacific Coast, Total	4.1	23.7	7.8	18.0	40.5	5.9
Metropolitan	2.7	25.4	7.6	18.5	42.3	3.5
Other	13.5	12.5	9.2	14.6	28.6	21.6
Northern Plains	16.9	12.5	18.9	22.7	21.9	7.1
Metropolitan	22.3	10.6	17.8	21.4	20.5	7.3
Other	5.4	16.5	21.4	25.5	24.8	6.5
Southern Plains	11.1	21.6	17.8	17.4	26.6	5.4
Metropolitan	10.6	21.9	19.3	15.0	27.8	5.3
Other	12.3	20.7	13.8	24.1	23.5	5.7
Southeast	13.0	11.7	22.7	25.9	20.8	5.9
Metropolitan	14.0	9.0	24.7	29.5	17.0	5.6
Other	11.7	15.7	19.7	20.8	26.2	5.9
Central	28.5	27.7	18.0	13.2	11.0	1.6
Metropolitan	32.8	29.2	18.7	10.3	8.7	1.2
Other	15.6	22.2	15.4	23.9	19.7	3.2
Northeast	16.4	26.3	20.9	22.5	9.5	4.4
Metropolitan	14.3	27.8	22.7	22.7	8.3	4.3
Other	29.4	17.4	9.8	21.3	16.6	5.5
U. S.	12.7	23.0	17.0	18.9	20.7	4.4

In the period 1962-1968, the average daily loading of public waste treatment plants increased some 4.1 billion gallons. Total available waste treatment capacity increased 6.9 billion gallons. (cf. Table 24. The table is based on the roughly 50% of all waste treatment plants for which both design capacity and average daily loading were reported in the respective Municipal Waste Inventories. The sample was scaled to an approximate total on the basis that the distribution of capacity to loading for all plants was similar to that for reported plants in the metropolitan and non-metropolitan categories within each region.)

Thus for every two gallons of added sewage, more than three gallons of added capacity was installed. The relationship can, perhaps, best be viewed by a simple comparison of annual rates of expansion. Between 1962 and 1968:

Population provided with sewer services increased 2.7% a year;
Waste treatment plant hydraulic loadings increased 3.2% a year;
Waste treatment plant capacity increased 4.0% a year;
Idle waste treatment plant capacity increased 6.1% a year.

That set of numbers does not adequately reflect a significant feature of the idle capacity phenomenon. To fully appreciate the force of the trend that is apparently in effect, one must take into consideration the fact that 76% of all of the plants in operation in 1968 were also in operation in 1962, and that much of the growth of loadings occurred in such plants. Incremental idle capacity, as reported, is offset to some extent by the takeup of idle capacity in plants already in place. In logic, the total amount of excess capacity should begin to decline as a result of progressive utilization at some indeterminate point when the total stock of available capacity exceeds 50% of the required stock. Whatever that point may be, we have not reached it. Unused capacity as a percentage of total capacity and of utilized capacity continues to grow.

There are distinct and obvious penalties inherent in this situation. The cost of the construction project is increased materially---though not proportionately--by overbuilding, as are the costs of operating and financing the project. Assuming the substitutability of uninvested capital in one place for another, and a generally fixed level of funding, overbuilding at one set of points at the same time that untreated waste discharges and overloaded waste treatment plants occur at other points contributes to the persistence of pollutional conditions. Up to 80% of the cost of construction is now borne by Federal and State governments. The amount of such assistance that is used to

TABLE 24
SHIFTS IN UTILIZATION OF WASTE TREATMENT CAPACITY 1962-68

MILLION GALLONS PER DAY

Region	Net Overloading			Utilized Capacity			Idle Capacity		
1. Metropolitan Areas	1962	1968	Shift	1962	1968	Shift	1962	1968	Shift
Pacific Coast	61.4	20.0	-41.4	2148.3	2409.6	+261.3	881.0	1628.9	+747.9
Northern Plains	85.8	61.6	-24.2	999.4	1479.7	+480.3	213.7	771.8	+498.1
Southern Plains	77.5	59.7	-17.8	860.4	1211.0	+350.6	399.2	662.8	+323.6
Southeast	75.1	107.8	+32.7	921.1	1350.2	+429.1	410.5	683.9	+273.4
Central	1034.1	1821.4	+787.3	4243.0	6021.6	+1778.6	1102.8	961.4	-141.4
Northeast	624.7	124.2	-500.5	4243.7	4041.5	-202.2	1017.9	1526.6	+508.7
Metropolitan Totals	1958.6	2194.7	+236.1	13,415.9	16,513.6	+3097.7	3965.1	6175.4	2210.3
% Shift			+12.1%			+23.1%			+55.7%
2. Non Metropolitan									
Pacific Coast	51.4	36.5	-14.9	438.2	481.7	+43.5	237.6	377.8	+140.2
Northern Plains	82.0	48.5	-33.5	572.3	580.5	+ 8.2	243.8	351.5	+107.7
Southern Plains	33.7	43.4	+ 9.7	452.2	561.7	+136.5	228.0	293.2	+ 65
Southeast	46.5	52.3	+ 5.8	679.2	1015.2	+336.0	350.4	562.0	+211.6
Central	52.8	55.6	+ 2.8	696.3	906.9	+210.6	398.1	402.2	+ 4.1
Northeast	66.4	134.4	+68.0	492.7	771.1	+278.4	157.3	258.1	+100.8
Non-Metropolitan Totals	332.8	307.7	+37.9	3303.9	4317.1	+1013.2	1615.2	2244.8	+629.6
% Shift			+11.4%			+ 30.7%			+39.0%
U.S. Totals	2291.4	2565.4	+274.0	16,719.8	20,803.7	+4110.9	5580.3	8420.2	+2839.9
% Shift			+12.0%			+ 24.6			+ 50.9%

capitalize idle capacity when it might be alloted for productive purposes can under conditions of resource scarcity only be considered to contribute to the persistence of pollution, since, unlike local funds, it is potentially available for a number of other projects. The effect of that misallocation is most evident when one considers the fact that both overloading and idle capacity increased between 1962 and 1968; and that if only 10% of the surplus capacity installed during the period had gone instead to points of more immediate need, reported overloading of waste treatment plants could have been eliminated. (cf. Table 24.) Finally, capacity in place limits the flexibility of a community in adjusting to changing conditions including improvements in technology and requires regular capital expenditures to sustain operating efficiency. Such overhead penalties are an inescapable result of any capital investment. The effect of surplus capacity is to add unnecessarily to the overhead burden and to tie the owners to a less manageable fixed cost base.

The tendency to overbuild is a general one; though it seems to be most strongly in force in the Pacific Coast States, where almost 24% of total idle capacity was located in 1968. With the exception of the Southern Plains region, the relative prevalence of idle capacity is greatest in non-metropolitan areas. Though the 1962-68 trend was for greater relative growth of surplus capacity in metropolitan than in non-metropolitan areas, the 1962 surplus in non-metropolitan areas was great enough that the proportion of capacity utilized at less than half design rating in 1968 remained greater in non-metropolitan communities in most of the Nation. Thus the excess, ostensibly installed largely to provide for future growth of service, tended to be located where growth is less pronounced. (cf. Table 25.)

Dollar Costs of Idle Capacity and Sewer Promotion

It is probably safe to assume that the major costs of misallocating funds to purposes that have a low marginal utility--specifically, adding to the stock of idle waste treatment capital and sewering portions of communities that do not require sewering--are borne by the environment. Continued pollution of water is the prime price that the economy pays for directing investments into projects that offer a low return relative to other, more directly profitable, purposes.

But if environmental costs are of great, if unmeasurable, magnitude, dollar costs are by no means inconsequential. And they can be estimated. Another section of this report will examine the impact of excess

TABLE 25
UTILIZATION OF METROPOLITAN AND NON-METROPOLITAN WASTE TREATMENT CAPACITY
1968

Utilization Rate	No. of Plants	Million Gallons/Day Capacity	Million Gallons/Day Utilization	Percent of Total Plants	Percent of Total Capacity	Mean Utilization Rates
1. Metropolitan Areas						
Overloaded	502	2200.2	3701.4	17.8	16.2	168.2%
80-100%	593	3300.9	2953.5	21.1	24.3	89.5%
67-79.9%	384	2384.4	1717.9	13.6	17.6	72.1%
50-66.9%	526	2457.4	1412.7	18.7	18.1	57.5%
25-49.9%	550	2730.2	1099.1	19.5	20.1	40.3%
<25%	262	498.3	59.8	9.3	3.7	12.0%
TOTAL	2817*	13,571.4	10,944.4			80.6%
TOTAL - excluding overloaded plants	2315	11,371.2	7,243.0	82.2	83.8	63.7%
2. Non-metropolitan Areas						
Overloaded	710	599.0	781.4	15.1	15.0	139.8%
80-100%	904	671.7	600.4	19.2	18.0	89.4%
67-79.9%	761	563.8	409.3	16.2	15.1	72.6%
50-66.9%	1030	813.4	471.4	21.9	21.8	58.0%
25-49.9%	1012	857.2	388.9	21.5	22.9	45.4%
25%	287	271.3	40.9	6.1	7.3	15.1%
TOTAL	4704**	3736.4	2692.2			72.1%
TOTAL - excluding overloaded plants	3994	3177.4	1910.8	84.9	85.0	60.1%

*of 4294 total plants
**of 8069 total plants

capacity on local operating cost structures. At this point it is concerned with the amount of the diversion of capital to relatively unproductive excess capacity and sewerage expansion.

Dollar value penalties of idle capacity have been calculated for both 1962 and 1968 by means of an uncomplicated, mechanical evaluation process.

The Municipal Waste Inventory for each year was scanned, State by State, with a digital computer. Wherever both design capacity and actual daily loading were recorded, the cost of building a plant of the given design size and general description (activated sludge, primary, trickling filter, oxidation pond) was calculated by the computer on the basis of the size to unit cost relationships developed by Robert L. Michel in Construction Costs of Municipal Wastewater Treatment Plants (U.S.D.I., FWQA, Washington, D.C., September 17, 1969). Where actual daily loading was less than 80% of rated capacity, the cost of the same type of plant, sized at 125% of average daily loading (80% operating rate) was also calculated. The differences between the two sets of values were summed, and the regional sums were scaled to include all plants on the basis of the assumption that the distribution of capacity was similar for all plants and for reported plants. Values are presented in Table 26 as the "under utilization-penalty".

Penalties are assessed in terms of national average prices, a moderate (25%) allowance for growth of demand, and they include full consideration of the economies of scale that exist in the cost to size relationships observed for waste treatment plant construction. In total, the dollar value penalty associated with plants operated at less than 80% of rated capacity in 1968 was $670 million, or 18% of the total value of public waste treatment plants.

Perhaps more significant than the total amount of the penalty is its trend. As noted earlier in terms of hydraulic capacity, the amount of capital incorporated in idle facilities increased substantially between 1962 and 1968. ($180 million in constant dollars, probably $205 million in value of actual dollar cost of construction projects, $260 million in 1970 replacement value.)

The calculated value of the incremental capital sunk into idle capacity between 1962 and 1968 does not, however, present the full amount of the penalty. Incremental idle capacity amounted to $180 million worth of waste treatment works. But the principal purpose of overbuilding is to provide for future growth, and in the aggregate the nation replaced every unit of idle capacity taken up by the growth process

TABLE 26
CAPITAL PENALTIES OF UNDER-UTILIZATION

	Millions of 1957-59 Dollars								
	1962			1968			Incremental Investment		
	Capital in Place	Under-utilization Penalty	%	Capital in Place	Under-utilization Penalty	%	Capital in Place	Under-utilization Penalty	%
Pacific Coast	364.8	81.5	23.3	474.3	109.9	23.3	109.5	28.5	26.0
Northern Plains	297.5	43.2	14.5	346.0	80.1	23.2	48.5	36.9	76.0
Southern Plains	503.2	86.4	17.2	594.0	104.9	17.7	90.8	18.5	20.4
Southeast	507.7	96.9	19.1	710.0	145.5	20.5	202.3	48.6	24.0
Central	689.3	108.2	15.7	869.9	114.5	13.2	180.6	6.2	3.6
Northeast	566.8	74.3	13.1	725.8	115.5	15.9	159.0	41.2	25.9
U. S.	2938.3	490.5	16.7	3719.9	670.4	18.0	781.6	179.8*	23.0

* actual cost, 1962-1968, based on average prices and construction rates in period, $205 million.

and added to it. Thus the total 1962-68 investment for unused capacity is distributed throughout the $670 million worth of idle capacity, and is not restricted to the $180 million increment. Put another way, in terms of the total economy, surplus capacity available in 1962 proved, on balance, to be totally useless to the nation over the next six years.

Given available information with respect to investment between 1962 and 1968, changes in the physical stock of capital, changes in the number of users of waste treatment facilities, and changes in the hydraulic loading of waste treatment plants, it is possible to assign the approximate distribution of the nation's capital investment between 1962 and 1968 to several broad categories of activity. The distribution, for the nation and for regional groupings of States, is presented in Table 27.

Total investment, in constant dollars, amounted to just over $2 billion for waste treatment plant construction, expansion, upgrading, replacement, and major modifications. (A significantly larger sum was invested in interceptor sewers, outfalls, pumping stations, and collection sewers. Such investments are not taken into account in this analysis.)

Recapitalization of existing facilities absorbed the lion's share of investment during the period. (cf. discussion pp. 13-25.) The fact is unexceptionable, given the high prevalence of waste treatment in 1962. The significance of the high capital overhead imposed by the size of the capital base is that less than 40% of capital made available for waste treatment plant construction during the period could be utilized to increase the aggregate level of control of wastes. Given the level of investment and of depreciation, a low marginal return was the best that the nation could anticipate, making the relative impact of any misallocation far more severe.

The attempt to quantify the marginal utility of the investment in terms of the various uses to which capital was applied involves analysis of reported growth in hydraulic loading of waste treatment plants and of population served by waste treatment plants. The total replacement value of waste treatment plants was calculated to have increased some $780 million, of which $180 million represented a net addition to idle capacity. To the utilized $600 million worth of facilities we can assign a series of functions, based on shifts in population connections and hydraulic loadings. (The assignments are

TABLE 27
DISTRIBUTION OF WASTE TREATMENT INVESTMENTS
1962 - 68

Purpose		Millions of 1957 - 59 Dollars, By Region						
	% of Total	PACIFIC COAST	NORTHERN PLAINS	SOUTHERN PLAINS	SOUTHEAST	CENTRAL	NORTHEAST	U.S.
Total Investment	100.0	185.2	210.1	177.3	383.3	502.4	589.4	2056.5
Recapitalization	62.0	75.7	161.6	86.4	181.0	330.8	439.4	1274.9
Treat Untreated Wastes (1)	4.4	12.9	4.6	3.4	36.9	10.9	22.8	91.5
'Normal' Growth of Sewering (2)	8.5	53.3	0.7	14.9	30.6	31.3	43.6	171.4
'Promoted' Growth of Sewering (3)	9.7	64.9	2.1	45.0	32.8	8.4	45.7	198.9
Incremental Industrial Wastes (4)	6.0	-62.8	1.3	9.6	60.1	214.8	-98.7	124.3
Relief of Overloading (5)	0.6	12.8	3.0	-0.6	-6.7	-100.1	104.4	12.8
Additions to Excess Capacity	8.7	28.5	36.9	18.5	48.6	6.2	41.2	179.8

less precise than that for idle capacity, since they depend on proportional techniques and do not scale factors into account.)

Reducing the number of sewered persons discharging raw wastes accounted for 4.4% of total investment between 1962 and 1968, and 11.7% of the capital available after recapitalization demand had been satisfied. Sixty-five percent of this kind of investment occured in the Southeast and the Northeast, where the bulk of the nation's population without treatment was concentrated through the period.

Providing treatment to meet demands presented by growth of sewer services accounted for 18.2% of total investment, 47% of investment available to extend treatment services. On the basis of the assumption that normal growth of sewer services should be proportional to growth of population,* more than half of this investment component was applied in the area of promoted or unnecessary sewering. Of the total amount of capital available for marginal extension of waste treatment, 25.4% was diverted to the purpose.

Increased treatment of industrial wastes exercised a claim on 6% of total capital investment, 20.7% of the net investment available after the recapitalization. The value attributable to incremental industrial demand for waste treatment services would have been much greater, except that there was a negative shift in demand in two regions, the Pacific Coast and the Northeast.

(That shift should not be construed to conflict with the tendency of factories to utilize public systems, in view of the method. Industrial waste loadings were deduced from per-capita discharge attributed to the sewered population, with loadings in excess of 100 gallons per capita per day assigned to industrial sources. Two quite logical explanations of the apparent decline in industrial usage come readily to mind. The nature of industrial specialization was changing in each region, moving away--in a relative sense--from heavy industry and first stage processing toward higher processing stages, fabrication, and low waste industries. The impact of that development is borne out by the fact that decline in reported per-capita discharge was limited to metropolitan areas in either region; non-metropolitan wastes per-capita continued to increase, suggesting the effects of connection of decentralized agricultural processing and pulp and paper production. Further, both areas have a fairly long history of public treatment of industrial wastes, at least as compared to the Southern Plains and the Central States. One of the characteristic features of municipal finance during the nineteen-sixties was establishment of user charges for public utility and other services, including sewer services. Industrial waste discharges are known to be highly variable and controllable; and the use of sewer service fees provides an incentive to industrial management to limit the volume of its discharges. So that, where industrial use of public systems had become established prior to initiation of fee systems or to the increase in fees required in many cases to finance system improvement or expansion, a reduction in gross volume of industrial discharge might be expected, even where the number of industrial connections was increasing.)

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*The assumption accounts in part for concentration factors by recognizing the differential growth rates of metropolitan and nonmetropolitan communities. That accounting was reinforced in computation by the constraint that in no case could growth be negative--after all, one can not move sewers from place to place.

Reduction of the incidence of overloaded waste treatment plants had almost no net impact on aggregate capitalization, due to a sharp increase in overloading in the Central States. Overloading declined markedly in the Northeast, and in a relative sense on the Pacific Coast, where little was reported in 1962; and it remained fairly constant in other areas. Individual expansion projects unquestionably reduced overloadings of many waste treatment plants during the period, but we deal here with net effects. And those expansion projects were apparently offset in the aggregate by the other factors evaluated--population growth, sewer promotion, industrial wastes. On a national basis, meaningful reduction of overloading occurred only with reduction of industrial waste discharges in two regions. There is a suggestion in the fact that the factors that govern the increase of waste loadings are to some meaningful extent unpredictable. If uncertainty does, in fact, play such a large part in distribution of growth processes, should not the strategy of installing significant amounts of excess capacity to support growth be subject to greater question?*

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* A note on method: the relationships discussed above were determined by use of the following formulae. Each formula is keyed to a numerical notation on Table 27.

(1) $$\frac{(R_2 - R_8)\,100}{C} \cdot I$$

where I = Constant dollar investment excluding value attributed to recapitalization and idle capacity

R_2 = Sewered population without treatment in 1962

R_8 = Sewered population without treatment in 1968

100 = Gallons per capita per day, the norm for domestic wastes

C = Increase in gallons per day of sewage throughput between 1962 and 1968

(2) $$\frac{[(P_2G) - P_2]\,100}{C} \cdot I$$

where P_2 = Sewered population in 1962

G = Appropriate growth factor, based on U. S. Bureau of Census population estimates, for metropolitan and non-metropolitan components of each regional grouping, subject to the constraint that $P_2.G$ may not be negative

(3) $$\frac{100\ P_8 - [(P_2 \cdot G) - P_2]\ 100}{C} \cdot I$$

where P_8 = Sewered population in 1968

(4) $$\frac{C - 100\ (P_8 - P_2)}{C} \cdot I$$

(5) $$\underline{O_2 - O_8} \cdot I$$

where O_8 = Net hydraulic overloading in 1968

O_2 = Net hydraulic overloading in 1962

OPERATION AND MAINTENANCE COSTS

Background

Operation and maintenance costs of waste treatment plans consist of expenditures for operators and technicians, power, chemicals and miscellaneous supplies. A previous volume in this series documented the magnitude of operations and maintenance costs; The Cost of Clean Water and Its Economic Impact, Volume I, FWQA, U. S. Department of the Interior, 1969. Furthermore, it was reported then that there has been a failure to appreciate the magnitude of this cost and rather to concentrate on plant investment. Further statistical analyses summarized here, indicate that annual operating and maintenance expenditures have been somewhat underestimated in previous reports. The revised estimates are that in 1962 operating and maintenance costs totalled $185.7 million (1962=100) and that in 1968 the total was $230.0 million (in 1962 dollars), a 23.8 percent increase. The objective of this chapter is: to reevaluate the method of measuring these costs; to recalculate the total amount of annual O&M costs; and to evaluate the relationship between the size of the treatment plant, the degree of utilization of the plant, and the resulting costs of operating and maintenance.

Annual operation and maintenance (O&M) expenditures should be considered as a short run cost rather than a long run cost. Traditional methods of estimating O&M costs have assumed that these costs were of a long run nature. The approach used in this chapter assumes that O&M costs are short run, the basic difference being that the plant size is fixed in the short run while in the long run it is allowed to vary. This method of estimating O&M costs provides an O&M cost curve for each plant size category. Thus the O&M cost for treatment plants of different sizes within the U.S. can be estimated. Also, this approach provides a framework for evaluating the excess cost incurred for constructing a plant that has a larger capacity (size) than is needed at a given time.

The 1969 Cost of Clean Water report also discussed factors tending to lead to an increase in operating costs on a national aggregate basis not the least significant of these are the pressures for improved operational efficiency. This analysis does not address an optimum level of operation and maintenance expenditures

However, in the face of a significant total increase in this area, the inefficient use of operation and maintenance expenditures becomes more critical. The section therefore concerns itself with more efficient allocation of such funds within the context of a growing expenditure.

Determinants of Operating and Maintenance Costs

A number of factors influence the level of operating and maintenance costs of a sewage treatment plant. First, as the degree of treatment becomes higher for a given concentration of wastes in the influent, operating and maintenance costs will increase.

Second, the operating and maintenance costs vary with the type of treatment and the waste characteristics to which applied. Technological characteristics differ among treatment types which, in turn, will lead to corresponding differences in costs for different rates of flow, quality of effluent, and geographical characteristics. For example, for 85 percent BOD removal at an average flow rate of 15 million gallons per day (MGD) with a highly concentrated influent, an activated sludge process may prove to be less expensive to operate than a standard rate trickling filter, but at a considerably lower flow rate with a less concentrated influent, the standard rate filter would probably prove to cost less to operate and maintain than an activated sludge process. Within a given category of treatment, no simple ordering of process types by operating and maintenance costs is possible, but given the full characteristics of the waste treatment needs of a community, one type of treatment will generally yield the minimum attainable level of operating costs consistent with a desired effluent quality. Population density and the mix of industrial activities are two rather obvious features that partially determine both the hydraulic loading and waste concentration demands on a treatment plant and, thus, partially determine the level of operating and maintenance costs of the plant.

Third, the location and geographical characteristics of a community will, in part, determine the level of operating and maintenance costs that the community will experience subsequent to the installation of a waste treatment plant. Among the locational factors influencing operating costs are the prices of power and personnel and the general level of prices facing the community. Climatic conditions affecting operating costs include thermal patterns and the frequency, duration, amount and intensity of precipitation. Topographic characteristics can sometimes affect treatment plant costs, particularly pumping and transmission costs. Ascertaining the specific impact of these locational and geographical factors on the costs of operating and maintaining a treatment plant is beyond the scope of this study, but it is necessary to recognize that they are part of the complex of determinants affecting the levels of operating and and maintenance costs.

Finally, an additional determinant of a treatment plant's operating and maintenance costs which has not generally received attention is the interaction between the design capacity of the plant and the actual rate of capacity utilization of the plant. The design capacity of a plant can be identified as the rate of flow that the plant can treat, at a desired degree of waste removal. It is also the rate which is expected to yield the lowest unit costs of operation and maintenance. For an operating plant of given design capacity, with the exception of some stabilization ponds, certain costs are necessarily incurred. A minimum amount of personnel is required for operation, maintenance and surveillance. To not maintain minimum numbers of personnel is to risk plant breakdown and to sacrifice quality of effluent. In order that chemical treatments have their intended effects on influent, certain minimal chemical feed rates depend not only on the actual flow into the plant but also on the volume and surface area of the tanks in the plant. Even at the lowest rates of capacity utilization, a minimum level of power consumption is necessary for the treatment plant to be operative. All of these minimum technological requirements imply that a treatment plant will incur a necessary minimum level of operating and maintenance costs, and these costs are a direct function of the design capacity of the plant. Such costs are referred to as overhead costs.

Overhead costs increase as the design capacity of a treatment plant increases, other things being equal. A bigger plant simply requires larger minimum amounts of personnel, chemicals, and power. Up to a point in the neighborhood of design capacity, then, for a treatment plant of a given type and design capacity, unit operating and maintenance costs should decline with increased plant utilization. As utilization increases from lower rates toward 100% of design capacity, the overhead costs are spread over a greater average daily flow and input units become more effective. Conversely, unit operating and maintenance costs should rise as the rate of capacity utilization declines below design capacity. This cost behavior is illustrated in Figure 6 and 7 by the statistically estimated cost functions for primary treatment and trickling filter treatment plants of 2.5 and 10 MGD design capacity.

In the range of zero to fifty percent of capacity, unit costs decline rapidly and begin to level off thereafter and the unit cost curve for the larger plant lies above that of the smaller plant, in the ranges depicted, reflecting cost differences between design capacities.

Thus, it is clear that in addition to the degree of wastewater treatment, treatment plant technology, and the hydraulic and geographical characteristics of a community, the design capacity of a community's treatment plant, together with the actual rate at which the capacity is utilized, will have a significant bearing on the level of operating and maintenance costs that a community will experience. This last factor is important not only for the purposes of understanding the underlying determinants of operating and maintenance costs, but also provides, in part, a basis for assessing and evaluating the economic consequences of over-capacity in sewage treatment plants in the United States.

The Concept of a Penalty Cost

From an earlier disucssion in this volume, it is apparent that underutilization of capacity is the rule in the operation of sewage treatment plants in the United States. Taking eighty percent utilization of plant as benchmark for effective capacity utilization, it can be seen from Table 25 that in 1968 (the most recent year for which data are available) 61.1 percent of the plants in metropolitan areas

UNIT COST CURVES FOR PRIMARY PLANTS — 2.5 AND 10.0 DESIGN CAPACITY

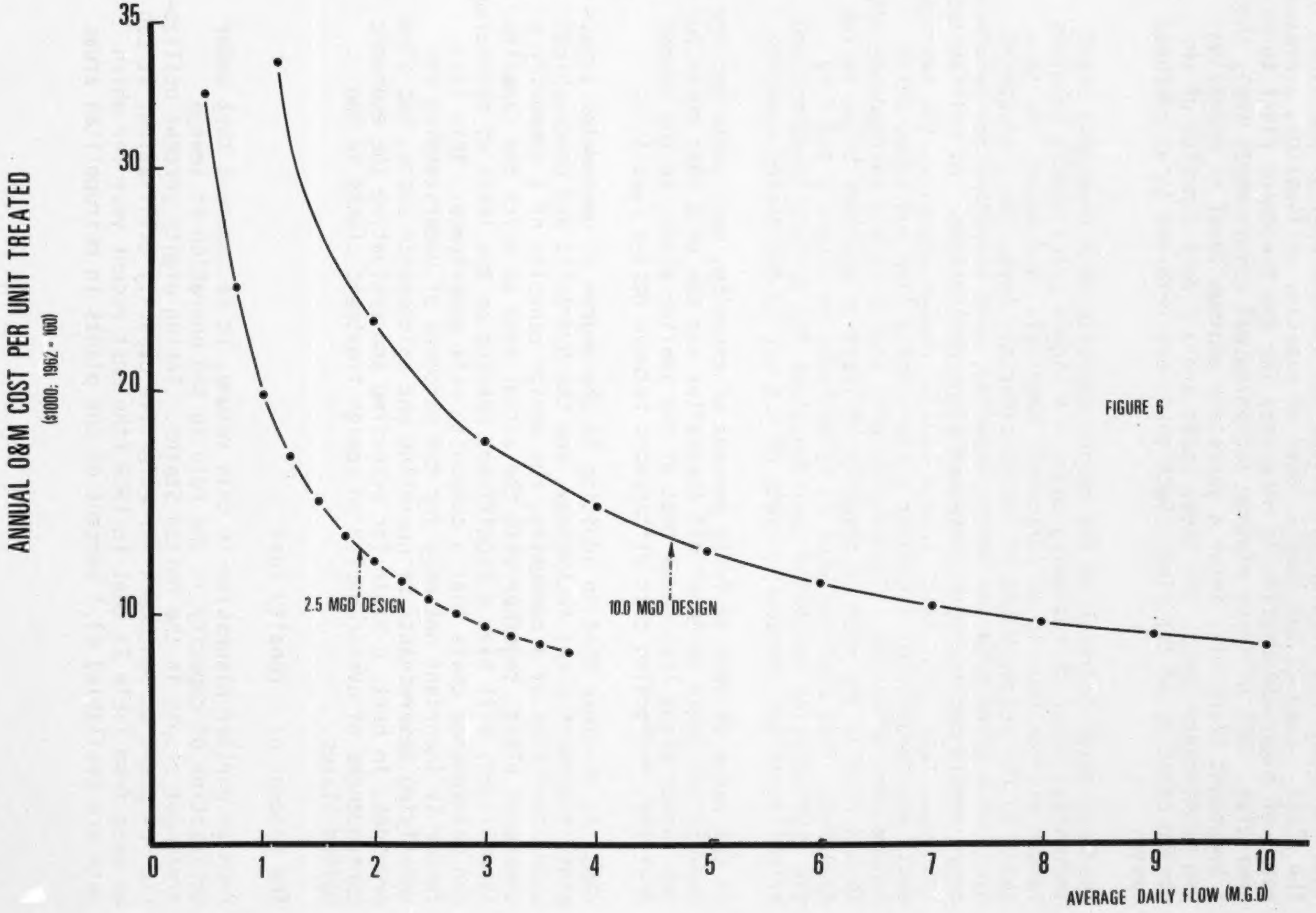

FIGURE 6

UNIT COST CURVES FOR TRICKLING FILTER PLANTS—
2.5 AND 10.0 DESIGN CAPACITY

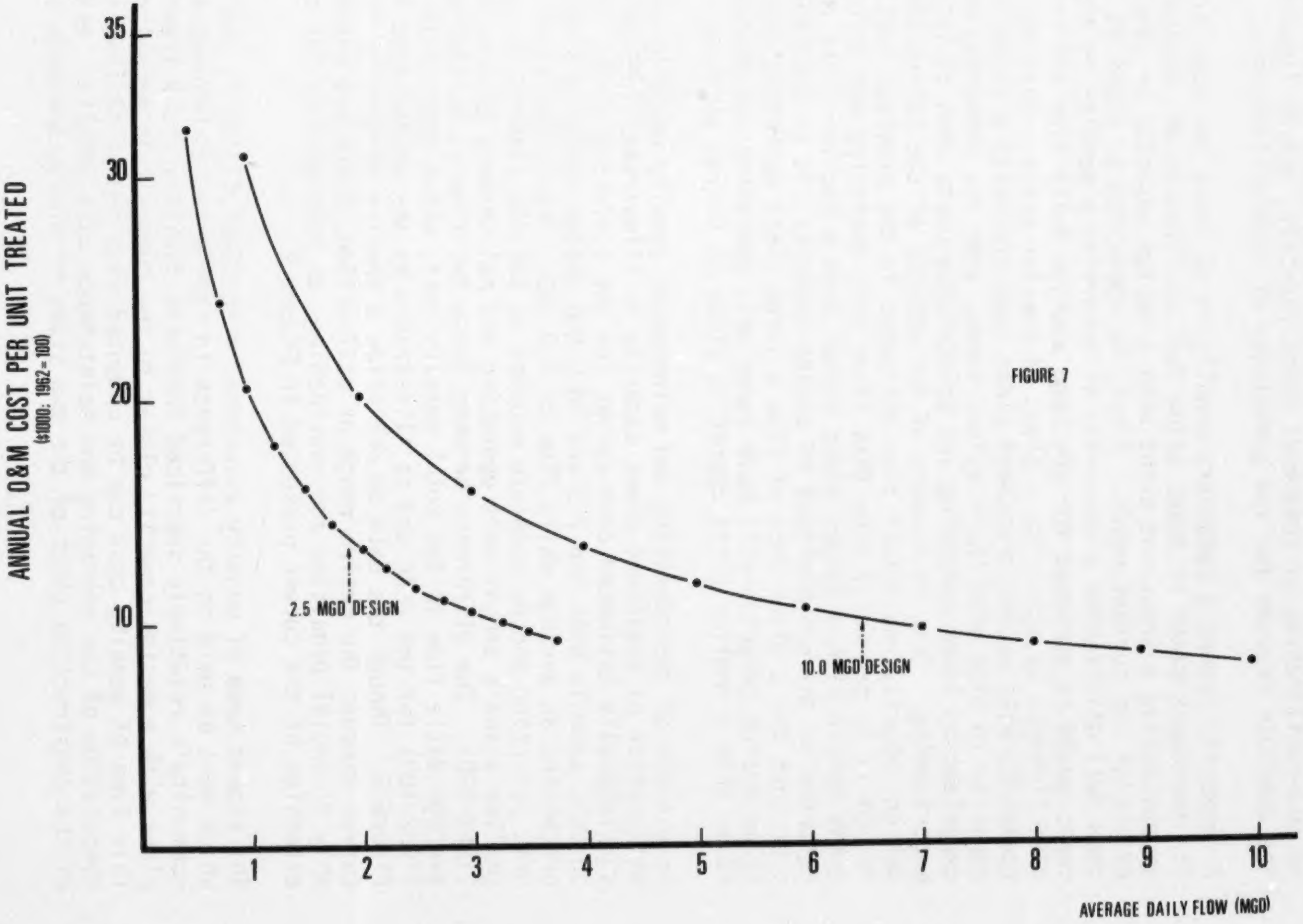

FIGURE 7

and 65.7 percent of the plants in non-metropolitan areas are operating at less than the eighty percent rate--82.2 percent of the metropolitan plants and 84.6 percent of the non-metropolitan plants operated below stated design capacities. It is of interest for this cost effectiveness study to attempt to assess the economic consequences of the prevalence of underutilization of treatment plant capacity, and to inquire as to the possible reasons for the prevalence of underutilization.

A community incurs a pecuniary penalty in at least two ways by operating its treatment plant at rates below full utilization or, equivalently, by possessing a treatment plant with a design capacity in considerable excess of its current needs. First, by operating a plant at less than full utilization a community is incurring a penalty in that lower costs could be achieved for the same average daily flow and treatment effectiveness by operating a plant of smaller scale. That is, had a community with excess treatment plant capacity built a plant of a design capacity in line with their actual needs, then the community would be experiencing lower operating and maintenance costs than it is currently experiencing. This is because of the effects of the interaction between design capacity and actual flow discussed in the previous section. Though it is generally true that lower unit operating and maintenance costs obtain with a larger plant rather than a smaller plant when operated in the neighborhood of design capacity, it is not usually the case that for a given rate of flow a large plant operating considerably below design capacity will have lower unit operating and maintenance costs than a smaller plant operating close to design capacity.

An example of the operating and maintenance penalty cause by underutilization of treatment plant capacity is illustrated in Figure 7 by statistically estimated cost curves for the activated sludge process. In this example both the 2.5 and 10.0 MGD design capacity plants are processing an average daily flow of 2.0 MGD. The larger plant requires unit operating and maintenance expense of $39,400 (1962=100) but the smaller plant's annual unit operating and maintenance expense is $20,600 (1962=100). The difference between these two figures multiplied by the average daily flow is the total penalty cost, which amounts to $37,600 (1962=100) for the year and is illustrated by the shaded area in Figure 8. Though the data do not allow a precise definition of cost curves through the entire range of utilization, there are unquestionably financial penalties for overloading, as indicated by the calculated extension of the curves presented in Figure 9.

The second type of penalty associated with overbuilding is the interest which must be paid on the difference in capital costs between a community's relatively oversized treatment facility and a treatment plant with a design capacity closer to the community's actual needs. This type of penalty cost can be computed in a manner similar to the computation of the operating and maintenance cost penalty: estimates of the construction costs of the two sizes of plants are made and an

ILLUSTRATION OF A PENALTY COST FOR ACTIVATED SLUDGE PLANTS

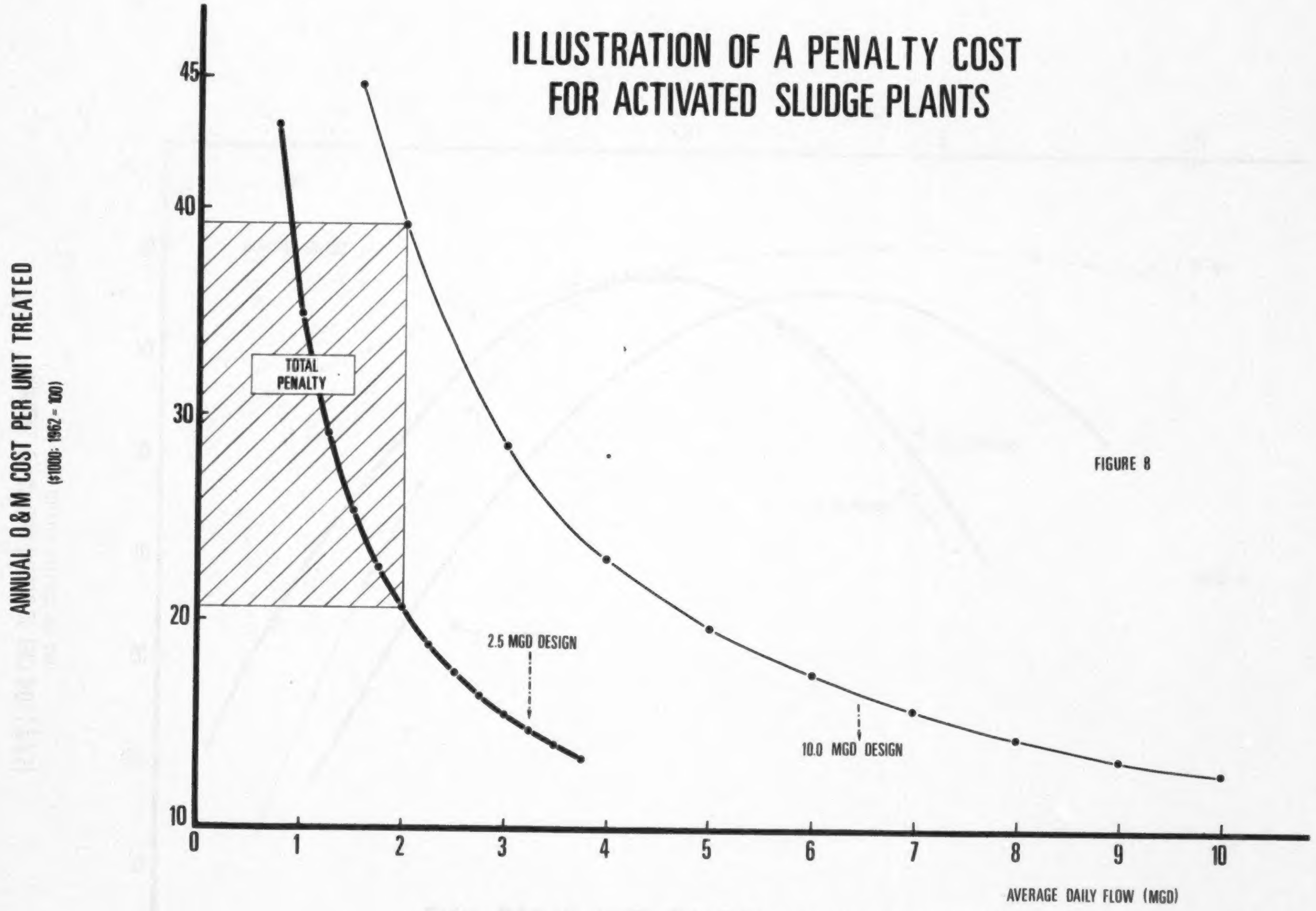

FIGURE 8

UNIT COSTS AND UTILIZATION OF CAPACITY

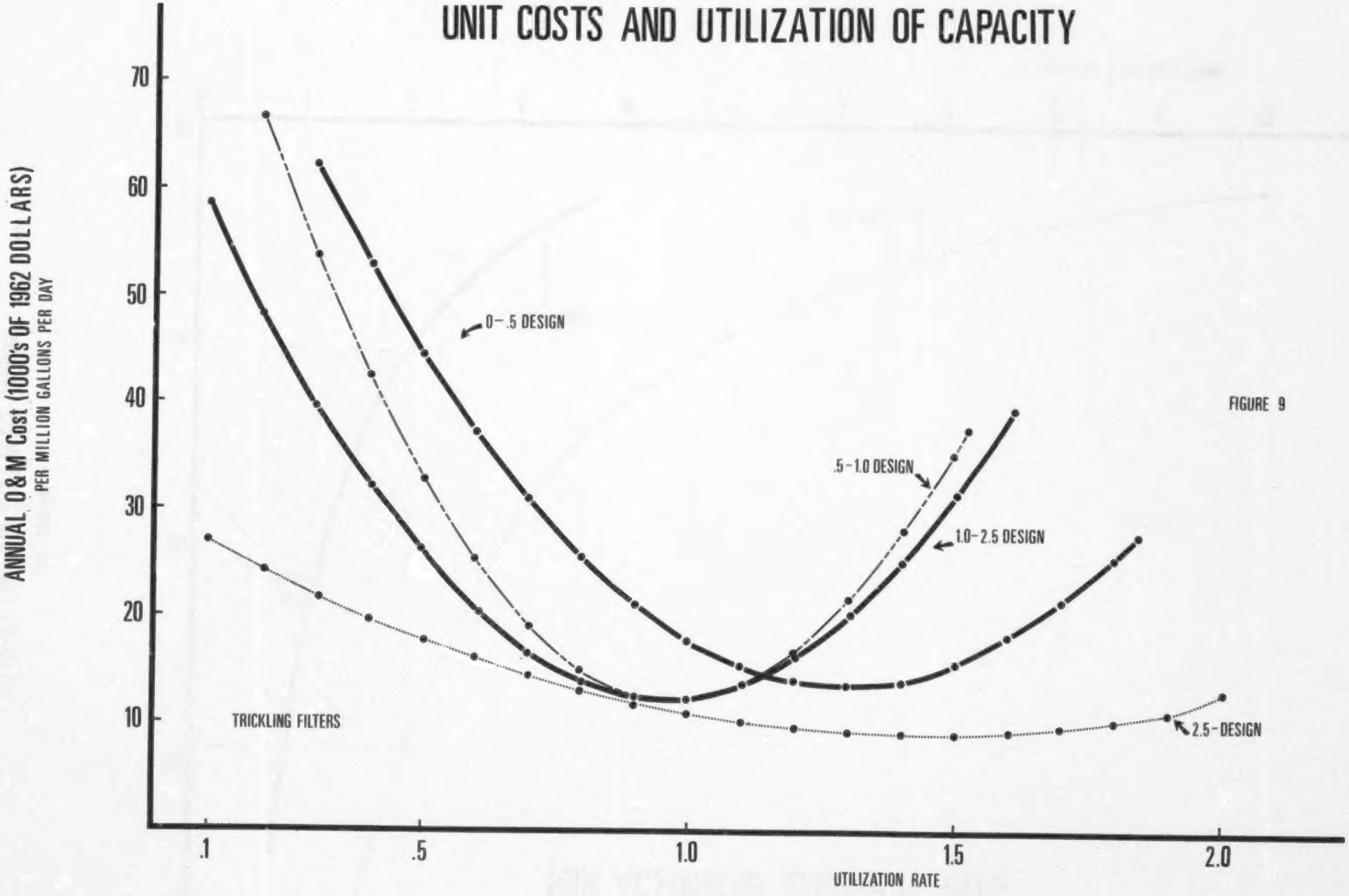

FIGURE 9

appropriate rate of interest is applied to the differences in costs; in order to determine the community's interest burden, a factor measuring the community's share of the financing is applied.

Adding the operating and maintenance cost penalty and the interest change penalty provides an estimate of a community's annual out-of-pocket expenses attributable to building a treatment plant with a capacity in excess of the community's needs. Although the underutilization penalty incurred by one community may not appear large when viewed for a single year, the aggregate value of all such penalties may be of a considerable magnitude; and the cumulative value of the community's penalties over time may prove to be of some significance. Thus, the next step in this study of cost effectiveness will be to utilize existing data to make estimates for the United States of the monetary penalty associated with the existence of excess capacity in sewage treatment plants.

Penalty Costs for Overcapacity

Absolute precision in estimating the costs of treatment plant overcapacity is unattainable for at least three reasons: First, actual operating and maintenance cost data are collected for only a relatively small number of plants; second, to derive the operating and maintenance costs that a community would obtain if it had a treatment plant with a design capacity in line with its actual needs would require detailed knowledge of the design characteristics of this hypothetical plant - this point also applies to the computation of the interest charge penalty-and third, no universally acceptable definition of full capacity utilization is available. In spite of these obstacles to precision, estimates of the costs of overcapacity can be obtained through the use of statistical procedures.

Through the use of data on operating and maintenance cost, average daily flow, and stated design capacity for a representative sample of treatment plants, operating and maintenance cost functions for various plant technologies have been statistically estimated. These cost relationships explicity include the interaction between average daily flow and design capacity as determinants of unit operating and maintenance costs. These relationships provide estimates of the unit operating and maintenance costs for a plant with stated average daily flow, design capacity, and plant technology which are statistically "best". Examples of the cost functions are illustrated in Figures 6 and 7 in the previous section.

In addition to providing an estimate of a plant's operating and maintenance costs, given its reported average daily flow and design capacity, the cost functions allow an estimate to be made of the operating and maintenance costs that an underutilized plant could achieve at its reported average daily flow, but with a plant of design capacity more in line with its actual needs. The difference between the former and latter quantities is an estimate of the operating and maintenance cost penalty incurred by the underutilized plant in question. Estimates of the operating and maintenance cost penalties for the entire United States for the years 1962 and 1968 have been derived for treatment plants having needed data reported in the 1962 and 1968 municipal waste inventories. These figures were adjusted by an appropriate scaling factor to account for plants not having necessary data reported in the inventory.

By a procedure analogous to the one described above, interest charge penalties caused by overbuilding of treatment plants have been estimated. Statistical investigations of capital cost functions for treatment plants which have been made make it possible to estimate the cost of building a given plant with a given average daily flow and the cost of building a plant designed to operate at a rate closer to full utilization. The difference between the former and latter magnitudes is an estimate of the total construction cost penalty caused by overbuilding. Multiplication of this aggregate figure by an average rate of interest will indicate roughly the total interest burden caused by overbuilding.

In Table 28 estimated operating and maintenance cost penalties, by regions and for the nation, are reported. Eighty percent has been taken as the benchmark of full utilization; that is, the operating and maintenance cost penalties have been calculated only to the degree that treatment plants were operating at less than eighty percent of their design capacity. The estimate for the entire United States is not large in magnitude for either 1962 or 1968: for 1962 the amount of annual operating and maintenance costs that could have been saved by building plants that could serve communities' needs at a rate of utilization of eighty percent is just under $14 million (1962=100) and the analagous figure for 1968 is just over $19 million (1962=100). On a per capita basis, the estimated operating and maintenance cost penalty for 1968 amounts to roughly 22 cents per person served per year.

Though the magnitudes of the operating and maintenance cost penalties are slight, both in absolute and per capita terms, it should be noted that these penalties amounted to 14.1 and 15.0 percent of the operating and maintenance costs of underutilized plants in 1962 and 1968, respectively. That is, underutilized plants, on average, could have reduced operating and maintenance costs by 15 percent in 1968 by having built plants in line with their actual treatment needs. The possible cost savings by utilization categories are reported in Table 29. The incidence and relative magnitude of operating and maintenance cost penalties are notable. As can be seen in this table, the relative penalty increases as capacity utilization decreases, increasing from 4.4 percent for a range of utilization between 60 and 80 percent up to

TABLE 28

ESTIMATED OPERATING AND MAINTENANCE COST PENALTIES FOR PLANTS OPERATING AT LESS THAN FULL CAPACITY

($ Millions, 1962=100)

	1962		1968		
	$ Millions Penalty	Percent of Total O&M	$ Millions Penalty	Percent of Total O&M	Annual Rate of Increase
Pacific Coast	3.04	14.4	3.69	17.5	3.3%
Northern Plains	.99	12.6	1.99	13.1	12.3%
Southern Plains	1.70	16.1	2.14	16.3	3.9%
Southeast	2.58	17.1	3.78	15.4	6.6%
Central	3.12	14.0	3.43	13.0	1.6%
Northeast	2.35	11.3	4.31	15.3	10.7%
U. S.	13.76	14.1	19.33	15.0	5.8%

TABLE 29

INCIDENCE OF OPERATING AND MAINTENANCE COSTS PENALTIES BY UTILIZATION CLASSES, 1968
(Utilization defined as average daily flow/design capacity)

Utilization Range	0 - .2	.2 - .4	.4 - .6	.6 - .8
Penalty as a percentage of O&M costs	59.8	32.8	14.6	4.4
Share of total penalty	21.6	31.5	33.8	13.4
Percentage of all plants	5.6	15.1	24.3	24.0
Percentage of underutilized plants	8.2	22.1	35.7	33.9

59.8 percent for the range zero to 20 percent. At around 60 percent capacity utilization, the cost penalty begins to become marginal, being equal to about ten percent of total operating and maintenance costs. With regard to the incidence of cost penalties, plants working at less than 40 percent of capacity account for 53.1 percent of the total penalty costs but only account for 20.7 percent of all plants. Thus, though the total monetary burden stemming from operating and maintenance cost penalties is not massive, it is generally not in a community's interest to build treatment plant capacity far in excess of its needs.

The other source of additonal costs to a community that arises from the existence of excess capacity is the additional interest that must be paid for the construction of excess capacity. In Figure 10 it can be seen that the estimated replacement value (rather than original cost) of treatment plant capacity, exclusive of land, interceptors, and outfalls, was $2.94 billion and $3.72 billion (1957-59=100) in 1962 and 1968, respectively. Of these totals, $490 million and $670 million went into excess capacity, using 80% as the full utilization benchmark. These latter amounts are represented by the shaded areas in Figure 10.

In order to estimate precisely the interest burden for communities with excess capacity, interest rates paid by communities and the communities' share of construction costs are necessary. For purposes of this analysis such precision did not seem warranted in view of the difficulty in assembling these data. Consequently, the total interest penalties have been calculated for a range of reasonable values for 1968, and are presented in Table 30. As can be seen in this table, the values range from $10.8 million to $25.1 million. On a per capita basis these estimates work out roughly to a range of $.12 to $.29 per person served per year. Thus, as in the case of operating and maintenance costs, the total and per capita interest costs incurred by overbuilding are of a rather small magnitude.

In spite of the small size of the estimated penalties it is worthwhile comparing them for 1962 and 1968 to discern any trends. First, it should be noted that excess capacity has been increasing between 1962 and 1968: 23% of non-replacement investment has gone into excess capacity (see Table 26) and the construction excess depicted in Figure 10 has increased from 16.7% to 18.0%. Second, operating and maintenance cost penalties relative to total operating and maintenance costs increased from 14% to 15% between 1962 and 1968. It appears, then, that there has been no tendency for the practice of overbuilding and its consequent costs to decrease. It is expected that total expenditures from all sources for treatment plant plant construction will continue to increase substantially over the next several years. Because excess capacity in public investments is indicative of a misallocation of resources, an examination of the possible causes for overbuilding in treatment plant construction should prove helpful in planning for the future growth of waste treatment facilities.

FIGURE 10

Replacement value of treatment plant capacity in 1962 and 1968 in $ billions (1957-59=100)

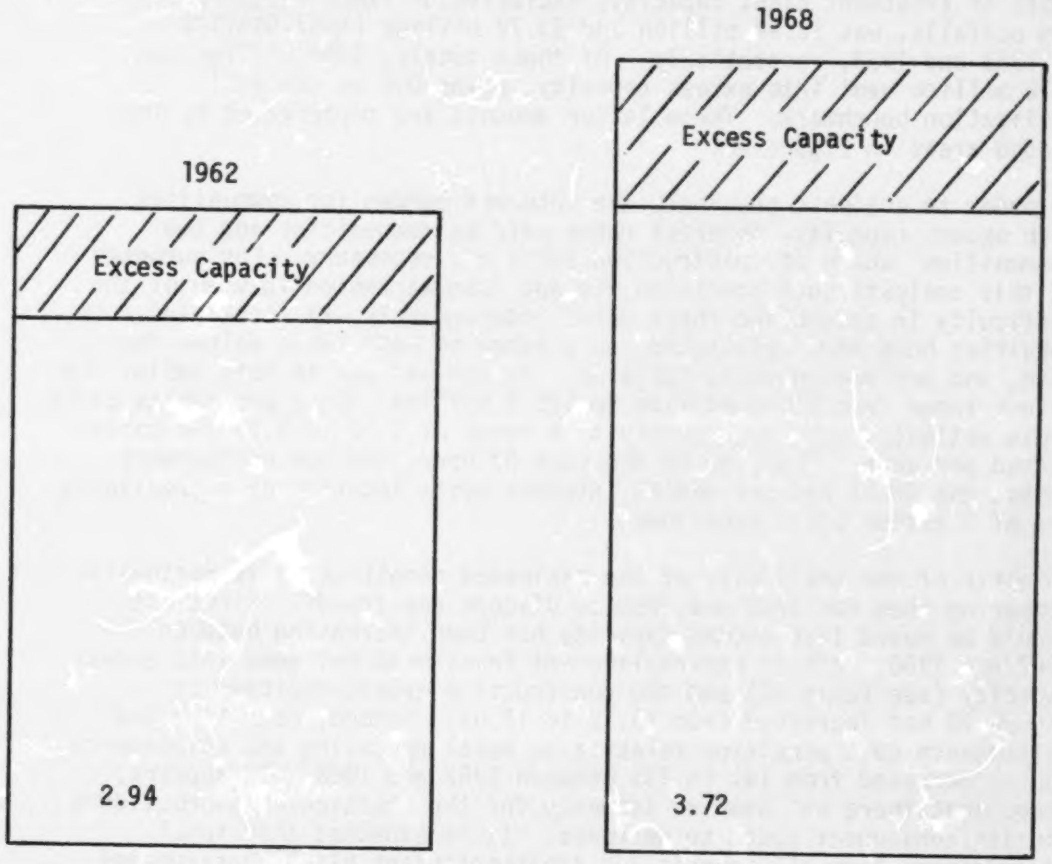

TABLE 30

INTEREST PENALTIES IN $ MILLIONS (1962=100) for 1968

	Interest Rates		
	.03	.04	.05
Community share			
.5	10.8	14.3	17.9
.6	12.9	17.2	21.5
.7	15.1	20.1	25.11

PLANNING DECISIONS AND INSTITUTIONAL BEHAVIOR

Background

Under a system of pure competition, economists postulate, the firm (or other economic unit) acts according to a set of desirable conditions. In the absence of non-market constraints, the firm will continue to produce up to the point where the cost of producing an additional unit of output--marginal cost--is equal to the average cost which, in turn, equals the price of the product. This pricing and sizing rule provides a minimal or least cost solution for the firm working under these conditions.

In the public sector--including the construction of waste treatment facilities--the allocation process is not guided by a market mechanism and relationships at the margin do not constrain decisions. Rather, institutional arrangements of a non-market nature determine the amount of goods and/or services to be produced and the price to be charged. The size of pollution abatement facilities is dependent upon myriad factors--population projections, waste projections, engineers' design rules, regulatory impositions, local aspirations and financial resources (including State and Federal grants). The pricing mechanism depends on an equally complex mixture of factors, ranging from the amount of wastes produced to assessed value of property.

The absence of an internally operating allocation scheme places the responsibility for maintaining optimal sizing and pricing rules within the controlling institutions. The institutional configuration should not ignore the principles of efficient and optimal resource allocation. Instead, it must first attempt to recognize how the institution affects the pattern of resource allocation, and when this pattern deviates from some predetermined optimum the allocation design should be altered.

The institutions that bear directly upon production decisions in the area of municipal waste handling include local government and the balance of local interest groups that determine its direction, local financial conditions as modified by Federal and State financial assistance, State regulatory boards, and the design-construction industry.

The explanation for the prevalence of waste handling diseconomies may be found in the fact that among these institutions, only one is so structured as to include economic efficiency among the values that go into the formulation of an optimum solution of a waste handling problem;

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and often this is manifested as a disinclination to finance waste facilities at all in the absence of legalistic incentives. Local finances are constrained by basic scarcity in the direction of efficient use of resources. None of the other institutional forces has any incentive to maximize investment utility.

State regulatory agencies, in general, have taken the position that waste treatment is a good and desirable thing; and that, all other things being equal, the more effective the treatment, the better the situation. Federal regulatory philosophy has generally concurred in, and sometimes run ahead of, the State attitude. The optimum solution for regulators, then, is one which includes the widest application of the highest degree of waste treatment.

The local government and the constituencies that give it legitimacy are often severely hampered in the decision process by lack of knowledge. Waste handling matters tend to assume complex technical configurations that are beyond the range of knowledge of the normal municipal agencies. Except in the case of the largest cities or consolidated metropolitan sanitary districts, local government's decision role tends to be limited to "sewer or don't sewer, treat or don't treat." Once a decision is made,and most often it is a forced decision stemming from Federal or State action, it is the prisoner of the regulatory agencies of higher levels of government and of its own consultants. Moreover--as we shall see--even the definition of its own financial self interest is altered by the administration of State and Federal grants.

The major thrust of this study has been to identify the pattern of the resource allocation process existent in the construction of pollution abatement facilities--in particular the construction of waste treatment and transmission facilities. Chapter II of this report describes the recognizable increase in the amount of sewering and treatment that occurred in the period 1945-1968. The incentive effect of Federal grants in achieving this dramatic upswing in construction activity is well documented. This section will analyze the allocation effect that controlling institutions have on investment in pollution abatement.

Federal Grants

Chapters V and VI of this study demonstrated that the capacity expansion (sizing) of treatment facilities was not optimal, except in terms of the postulated objectives of regulatory agencies and the construction industry. Excess capacity has been detected in a large number of plants, while in many cases under-capacity exists. The opportunity costs or penalties of excess capacity on a national basis have also been calculated. The circumstance to be analyzed in this section is the effect that Federal grants have had on the magnitude of this opportunity cost. Although this section considers only the relationship of Federal grants to excess capacity penalties, from a resource allocation standpoint, those plants with under-capacity are just as relevant. Because these under-sized plants not only incur an economic penalty, namely, higher average costs, they also produce an environmental penalty caused by lower removal efficiencies. Adequate information is not available at the present to estimate such penalties. Therefore, the analysis and conclusions drawn from this analysis may be considered to be biased to the low side because of the exclusion.

Since the passage of Public Law 84-660 in 1956, Federal grants have been continually increasing. Federal grants, and where existent, matching State grants have been a major impetus to communities to increase waste treatment construction activity. While increased investment activity, on the surface, demonstrates progress in the construction of waste facilities, the excess capacity prevalent in investment dilutes the effectiveness of the dollars expended. Therefore, in order to identify the effective impact of grants, the relationship between grants and excess capacity must be isolated.

Before this relationship can be analyzed, the fiscal environment in which grants are allocated must be understood. If expenditure levels for local government services increase at a rate equivalent to the post-1945 experience--and there is good evidence they will increase--while local revenue patterns, which are already extended, do not change, then local governments will be faced with increasing deficits. This fiscal pressure facing local governments has been acknowledged by the President in his statements on "Fiscal Federalism." Grants from Federal and State governments have become the prime methods of filling these gaps.

Pollution abatement programs are one reason for increased local expenditures. Public Law 84-660 was designed to alleviate some of the fiscal pressures created by this demand. This program specifically designates that certain types of local government expenditures for pollution abatement--projects related to treatment plants, interceptors and outfalls--are eligible to receive grant monies. Discussions in other parts of this report have pointed out that expenditures for those projects constitute only a portion of the funds needed for total water pollution abatement programs. Aside from determining the nature of expenditure to be supported, the grant component of Public Law 84-660 as amended has a prescribed life span, being scheduled to terminate in 1971. It would appear that a community faced with an increased demand for abatement facilities that is constrained by local fiscal pressures would seek grant aid. If the existence of the grant program is uncertain over the long run, and the investment categories are specified, then construction of excess capacity in the eligible categories is likely.

Another statutory element of the grant program that is likely to cause excess capacity is the allocation formula. The allocation formula of the existing program is based on a combination of State per capita income and population. If the needs for funds within a given State are not related to these allocation criteria, then over or under funding for the State may occur. Those States with an excess of alloted funds are likely to allocate the money on a less competitive basis than States near or below the level of funding where supply of funds equal demand. */

Excess capacity incentive effects of grants can be approximated by comparing investment trends, grant allocations and changes in excess capacity. The comparison will be made for the 1962-68 period. Earlier chapters estimated the opportunity cost due to excess capacity for both 1962 and 1968. While Federal construction grants have been made since 1957, the opportunity cost calculations for this earlier period are not available. The opportunity cost for plants operating at 80% or less of capacity in 1962 was 490 million dollars, while the opportunity cost for 1968 was calculated at 670 million dollars. One would expect the opportunity cost for 1962-68 to decrease in view of the high prevalence of treatment in 1962--as communities with excess capacity absorbed that capacity through a process of natural population and industrial growth. In fact, the amount of excess capacity became larger.

Aside from the penalties derived from excess capital costs, there is a related higher operation and maintenance cost for plants with excess capacity. Chapter VI developed and documented the concept that size, independent of the degree of utilization, does not necessarily produce economies of scale. Plants with excess capacity have higher unit operation and maintenance costs than smaller plants that are fully utilized. Where excess capacity is constructed, due to the availability of a Federal grant or other cause, the community will be faced with higher operation and maintenance costs. Similarly, if a community has

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*/ Review of Financing the Section 8 Construction Program, Federal Water Quality Administration, U. S. Department of the Interior, Office of Survey and Review, October 1970.

excess capital it will be paying interest on the excess capital investment. As interest rates rise such costs will constitute higher penalties. The operation and maintenance costs penalty together with the interest penalty constitute an annual penalty which, when cumulated, might offset the Federal fiscal aid provided for the capital expenditures. It should also be noted that grants are not allocated for operation and maintenance and interest payments. Therefore, the grant might initially help the capital investment position of the local entity, but distort its long run operating budget by causing communities to operate on the higher portion of their average cost curve.

Aside from the effect of encouraging communities to operate on an inefficient level of average cost, excess capacity constructed from grant outlays constitutes an opportunity cost for the larger economic community. This opportunity loss may be viewed either from a fiscal or an expenditure view. From the expenditure side, grant monies that go to communities with excess capacity are potentially diverting money from communities which need capacity in conditions of resource scarcity which have indeed prevailed with respect to Federal grant funds. When viewed fiscally, those communities which are constructing excess capacity with the help of Federal and State aid are able to finance this excess at the expense of citizens located outside the boundaries of the community in question. If a majority of the expense is financed by means external to the local entity, then the community's financial share of the facility is lessened. Thus, the average out of pocket fixed cost to the community is lessened by the grant financing.

Both economic losses--the opportunity costs and higher average variable costs--are demonstrated in the following example.

Consider a community of 8,500 persons that decides to build a waste treatment plant. The community's immediate need (and allowing for some short term growth) is for a 1 million gallon per day secondary waste treatment plant (high rate trickling filter, for the sake of example), that will have a useful life of 25 years and can be financed serially at 6% in a situation marked by 25% State and 50% Federal matching grants. Under these conditions, annual costs will be:

(1)	depreciation (capital cost)	$21,000	
	operation and maintenance	15,500	
	interest	15,800	
	Total	$52,300	(Assuming national average prices in 1962 dollars)

of that, the community's share will be:

(2)	depreciation	$ 5,250
	operation and maintenance	15,500
	interest	3,950
	Total	$24,700

If, instead of a 1 million gallon per day plant, the community decides to construct a 2.5 million gallon per day plant, then annual cost will be:

(3)	depreciation	$37,200
	operation and maintenance	20,500
	interest	27,900
	Total	$85,600 or 64% more;

of which the community's share will be:

(4)	depreciation	$ 9,300
	operation and maintenance	20,500
	interest	7,000
	Total	$36,800 or 49% more.

Regardless of the design size, the community will only have an immediate need for 1 million gallons of capacity per day, thus any capacity in excess of the needed capacity will be idle, at least initially. By obtaining grants, the community is capable of increasing the design capacity of the plant by 150% while the capital cost (depreciation) obligation increases by 64%. While the average fixed costs on a total cost basis is higher, Item 3 the average fixed cost incurred by the community out of pocket is lower, Item 4, and the difference in average fixed cost is charged against revenue sources extraneous to the community. When variable costs enter the analysis--and operation and maintenance--the financial picture is not as advantageous for the community. Total costs to the community increase by 50%, indicating that the capital cost advantage is more than cancelled by the increase in other costs.

The example is highly simplified, and the analysis is static; nevertheless, it does demonstrate the losses possible from a construction program that is structured without efficiency constructs.

In sum, the structure of the Federal waste treatment plant construction program does affect the allocation process of treatment plant construction. Both the specific categories eligible for funding and the temporal limitations of the program have created incentives that may be construed to modify capacity expansion practices. To the extent that this has occurred, the grants act counter to the basic concepts of efficient resource allocation. Either a more flexible or a more closely constrained program might encourage cities to define their system needs more accurately, and might enable cities to direct expenditures to meet these needs. Essentially, the design of the grant system must take into consideration the allocative effect of institutional constraints. This realization will be important for the duration of the construction grant program for waste facilities and for related future programs.

Local Governments

Policy and programs instituted on a Federal level which affect local and State governments must consider the behavior of the governmental units. The water quality program is determined on a national level, but the main participants in the program are the local entities. Thus a better understanding of the modus operandiof this level of government is essential to an effective program.

While a discussion of local government activity seems logical and while its importance seems obvious, there has been little organized research and analysis on the subject. Rather, this crucial phase of program analysis is often left to vague impressions of the analyst and/or decision-maker on the Federal level. Based on these particular impressions generalized rules of local behavior are postulated; and programs are formulated on the strength of the postulates. This section does not attempt to be a definitive work on the behavior of State and local government, a subject that needs to be researched further. Rather, it presents some hypotheses about local behavior and its effect on efficient allocation of resources.

A number of interesting hypotheses have been proposed by John M. Richardson, Jr. and Howard Maier of Case Western University.* Their research, based on a study of local governments surrounding Lake Erie, concludes that we have the engineering answer for most sewage problems. However, the optimum solution may not be implemented because of important intervening political factors. Examples of such political factors abound and form the core of the following hypotheses.

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* J. M. Richardson and H. Maier, "Incongruent Goals, Politics and the Pollution of Lake Erie," a paper delivered at the Fourth Annual Midwest Student Seminar on Urban and Regional Research, Northwestern University, April 24-25, 1970

(1) Each local governmental organization has as its chief goals: (a) continuation of its existence; (b) if possible, an increase in its power. Local governments often exist which are responsible for only one part of pollution abatement. Responsibility often overlaps. Such fragmented structures will carefully guard their existing functions, for should these functions be assumed by another governmental unit, their raison d' etre would disappear. While continuing to perform its distinctive functions, each local unit--at the same time--competes with other local structures for new functions being delegated to the local level. Such behavior is modified by a desire to maintain the unit's political autonomy and its relative importance vis-a-vis other local units. Maintenance of one's organization and the increase, where possible, of one's power constitute only one element of a situation in which local goals may conflict with a "best solution" to a given problem.

(2) Local government goals may conflict with the goal of a least cost clean environment because of the role played by personal goals in the decision process. Richardson studied a pollution problem having only two viable alternatives: a regional solution and a local solution. In his case study, the desire to represent community attitudes favored the local treatment approach. The goal of community protection was also seen by the local Mayor and city council as best served by the local treatment alternative. Clearly the decision-making process is not that simple. Goals may be congruent or conflicting, and their interrelationships greatly affect the policy outcome.

It is a general hypothesis of organization theory that a decision making unit having two or more conflicting goals will be most influenced by the more operational goal. And the more operational goal of the local government official may be assumed to be the one which satisfies the above hypotheses. Maintenance of political power or increased political gain, when in conflict with a goal to achieve a clean environment using a least cost solution, will dominate. Thus the priorities of those organizations supporting a least cost goal may often be in conflict with those of local government.

Further, if two goals are nearly equally operational, Richardson hypothesizes the dominance of the salient one for the decision-maker

For example, a local official's immediate political goals would dictate the choice of a continuing pollution problem rather than the choice of raising taxes significantly for a new treatment plant. For the ecologist, the options would presumably be reversed. Richardson and others point out that the local politican is not an ecologist; he is, rather, a person who identifies with his organization and whose goals are highly operational where the organization is concerned. In short, his predominant concern is with maintaining the existence of the organization and, where possible, with increasing its power.

The process of preserving the environment must operate within the political milieu described briefly above. The precepts of regionalism, systems, and comprehensiveness must contend with political impediments characteristic of government at all levels. In terms of resource allocation on a national scale, local behavior patterns add another dimension to the institutional constraints preventing the concepts of marginality from working. In the previous section the possible distortion caused by Federal activity was described. Because of constraints inherent in the grant allocation mechanism, misallocations occur and economic efficiency is hampered. Local government behavior also may prevent the optimum solution from being employed.

That optimum solution can be described in a theoretical way by taking the economic concepts of marginality which apply to the single firm, and extending the principles to the operation of the market having many firms. In theory, each firm (city) should be able to define the average and marginal costs of its treatment facilities. The market then combines these costs curves and derives a market share rule--which can be interpreted as a sizing or capacity expansion criteria--and a pricing rule. At a market level the marginality rules form the basis upon which these other rules are determined. The optimum solutions described by such a system are often thwarted by non-economic decisions. The least costly solutions, the comprehensive systems approaches, are usually not implemented.

The relationship between economic efficiency concepts and political decision making and its effect on the problem of capacity expansion will be translated into more real terms and illustrated by means of case study.

On a single community basis, in which the community has no neighbors, the capacity expansion problem involves an estimation of population growth, behavior of cost functions, (e.g., a recognition of economies of scale) operating cost levels, and decisions concerning uncertainty.

When regional concepts are introduced, the number of technical variables to be considered multiplies. Regionalism involves a new set of cost functions. The trade-offs between components of the system become greater; e.g., shall more interceptors be constructed, requiring more pumping but permitting a larger treatment plant to be constructed? Or is the plant of sufficient size so that unit costs actually increase as the plant size increases? There are technical bottlenecks which cause modal points in the definition of cost curves; at these points, either economies or diseconomies of scale occur. Technically it is feasible to estimate what the modal points are, and to make comparisons of the mix of alternatives. The environmental field has not been slow in adopting the kinds of systems analysis tools that were used so successfully in the space program. But once the cost functions are identified, the system is identified, and the market shares estimated, this allocation process breaks down and institutional constraints dominate.

Richardson and Maier demonstrate such a breakdown in implementation A city must increase the size of its treatment plant. Because the plant operates at full capacity or more, the city officials contemplated joining the system of the major city in the metropolitan area, which has developed a regional plan for the metropolitan area. As negotiations for a cooperating agreement began, the desire to preserve autonomy also began to grow. The mayor and council were faced with a dilemma: the existing plant site was limited--reached a point of diseconomies of scale--and cooperation with major city was undesirable to some local values. In the situation, local autonomy proved, rather than technological effectiveness or economic efficiency, to be the determining decision factor. A large number of case studies demonstrating the conclusion that institutional values of a non-economic--or even uneconomic--nature are critical could be repeated. Nor is local autonomy alone in producing sub-optimum problem solving. Health department rigidity, uninformed rate-making, established client relationships with engineering firms, industrial management's influence on local government--a host of organizational and sociological constructs stand between the technocrat's dream of efficiency and the real world of political decisions. This may be desirable for non-economic reasons but the costs should be assessed and the decision made on an informed rational basis.

Local Finance

A community's share of treatment plant construction cost is often met by issuing bonds. The issuance of bonds, though, must often be approved by the electorate of a community; and this necessary but desirable process can create problems for the efficient allocation of resources to water pollution control and abatement. Specifically, problems associated with local bond financing can induce municipal officials to build waste treatment facilities in considerable excess of their current and near-term needs, to reduce the occasions when they must go before the voters.

Alternative methods of dealing with treatment plant design uncertainty can be categorized into two broad strategies. First, a community can build a capacity which is far in excess of current needs, and as a consequence be reasonably assured that additions will not be needed for quite a number of years. Second, a community can build capacity to meet increases in waste treatment demands as these demands occur. The first strategy requires an initially large issuance of local debt, but with the anticipation of little or no subsequent issuance for a considerable length of time. The second strategy requires a lesser initial capital expenditure, but subsequent expenditures must be incurred at relatively frequent intervals. Several structural features of local finance tend to lead municipal officials to favor the first strategy over the second, because a number of problems are created by frequent bond issues for the same activity. Among those problems are: possible voter rejection because of frequent reappearance of proposals for the same purpose, the fixed costs associated with marketing a bond issue, and current uncertainty about future interest rates and inflationn.

Frequent reappearance of bond issues for the same program may make local voters suspicious of the program. Voters may feel that the program has been misrepresented in the past if the same bond issue reappears frequently and, consequently, may be led to seriously question the necessity of yet a further funding of the same program. Also, repetition of the same kind of bond issue may lead voters to assume that the program has not been conducted in the most effective manner in the past and that ineffectiveness should not be, in a sense, rewarded. To the extent that a significant number of members of the local electorate react in these fashions to a frequently repeated issue, local officials must weigh the risks of voter rejection of a frequently presented bond issue against the risks of rejection of one large bond issue. With respect to treatment plant construction, then, these considerations can lead local officials to opt for the strategy of overbuilding rather than adding increments to capacity to meet demand as it occurs.

After a bond issue is authorized by an electorate, the sale of the bonds must be effected. The sale is not a costless transaction. Rather, market information must be obtained and brokerage fees must be paid. Part of these costs are independent of the amount of the issue. The more frequently a community markets a bond issue, the more often these necessary transaction costs will be incurred. The implication of this feature of the financial markets for treatment plant construction bond issues may prove to be cheaper to administer than the alternative of marketing bond issues at more frequent intervals.

It is a well-established economic phenomenon that inflation creates the expectation of further inflation, along with an attendant anticipation of higher interest rates. Such expectations, in turn, lead to an acceleration in the purchase of durable goods and structures. Local officials are not exempt from this syndrome of inflation. With regard to treatment plants, an inflationary situation may induce a "big push" attitude: construct as large a plant as possible within political and financial limits before prices and interest rates rise further.

Thus, a number of problems associated with local bond finance lead to a bias toward overbuilding treatment plant capacity in many communities. But treatment plant overbuilding is just one of the many consequences attributable to the maladroitness of local finance in coping with ever increasing demands for public services.

Economies of Scale

Every published investigation of the relationship between treatment plant construction costs and design capacity has indicated that economies of scale in treatment plant construction exist. That is, as the design size of the plant increases, unit construction costs decline. These studies indicate that, over the valid size ranges, a 10% increase in design capacity will lead to an increase in unit construction cost in the range of six to eight percent, depending on the type of plant. */ It would appear, then, that for a given target treatment flow that it is less costly to build one plant rather than two or more plants to accommodate this flow. However, in assessing the potential economies in an actual system design, the costs of interceptors required to convey the wastes to a single plant must be considered. In addition, if existing facilities with remaining usefulness are to be scrapped in the process of moving to a large single plant, the salvage value of that facility must also be included in the analysis to reach a true cost effective solution.

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*/ See P.M. Berthouex and L.B. Pollowski, "Design Capacities to Accommodate Forecast Uncertainties," Journal of the Sanitary Engineering Division, Vol. 96, No. SA5, October 1970, pp. 1191. It should be noted that the costs exclude the costs of interceptors, outfalls, and land acquisition.

Previous studies of operating and maintenance costs for treatment have tended to substantiate the belief that there are economies of scale in treatment plant operation. The usual practice in these investigations is to statistically fit a relationship between annual unit operating and maintenance costs and average daily flow or design capacity (but not both) for a sample of treatment plants. Generally, the results indicate that unit operating and maintenance costs decline as the rate of flow increases.

In hopes of achieving the greatest economies possible, many communities have built treatment plants and/or added treatment plant capacity in considerable excess not only of their initial needs but also of their needs over the near future, say five to ten years. On the one hand, construction costs per unit of flow, and, thus, interest payments, should decrease with plant size. On the other hand, based on past investigations, community officials might expect to attain lower unit operating and maintenance costs with increasing plant capacity. Reinforcing the strategy of overbuilding is the apparent assurance of being able to meet the additional treatment needs caused by an increase in population growth. Thus, for reasons of economy and uncertainty it would appear that the practice of overbuilding treatment plant capacity rests on substantial economic and engineering grounds.

Upon closer investigation, however, the economic foundations for the practice of overbuilding are, in part, illusory and if not properly assessed will entail higher effective unit construction costs and operating costs than would be the case if the alternative strategy of building and adding treatment plant capacity in accordance with current and near-term needs was followed. First, lower construction and interest costs per unit of flow can only be achieved if a treatment plant is actually operating near or at its design capacity. (cf Figure 11) Chronic operation at less than full utilization will result in higher construction and interest costs per unit treated than would be the case with a smaller plant. Second, similar considerations apply to the proposition that lower unit operating and maintenance costs will necessarily be achieved with larger plant sizes. From the discussion in a previous chapter, it is clear that lower unit operating and maintenance costs may not be achieved with a plant capacity in considerable excess of actual needs. In fact, it is generally the case that for any given actual flow that can be accommodated, operating and maintenance costs will be higher for a larger plant than for a smaller plant. Economies of scale in operation will be attained only if a treatment plant is operated near its intended capacity.

UNIT COST CURVES FOR DESIGN CAPACITIES
of .5,1.0,2.5,5.0, and 10.0 MGD

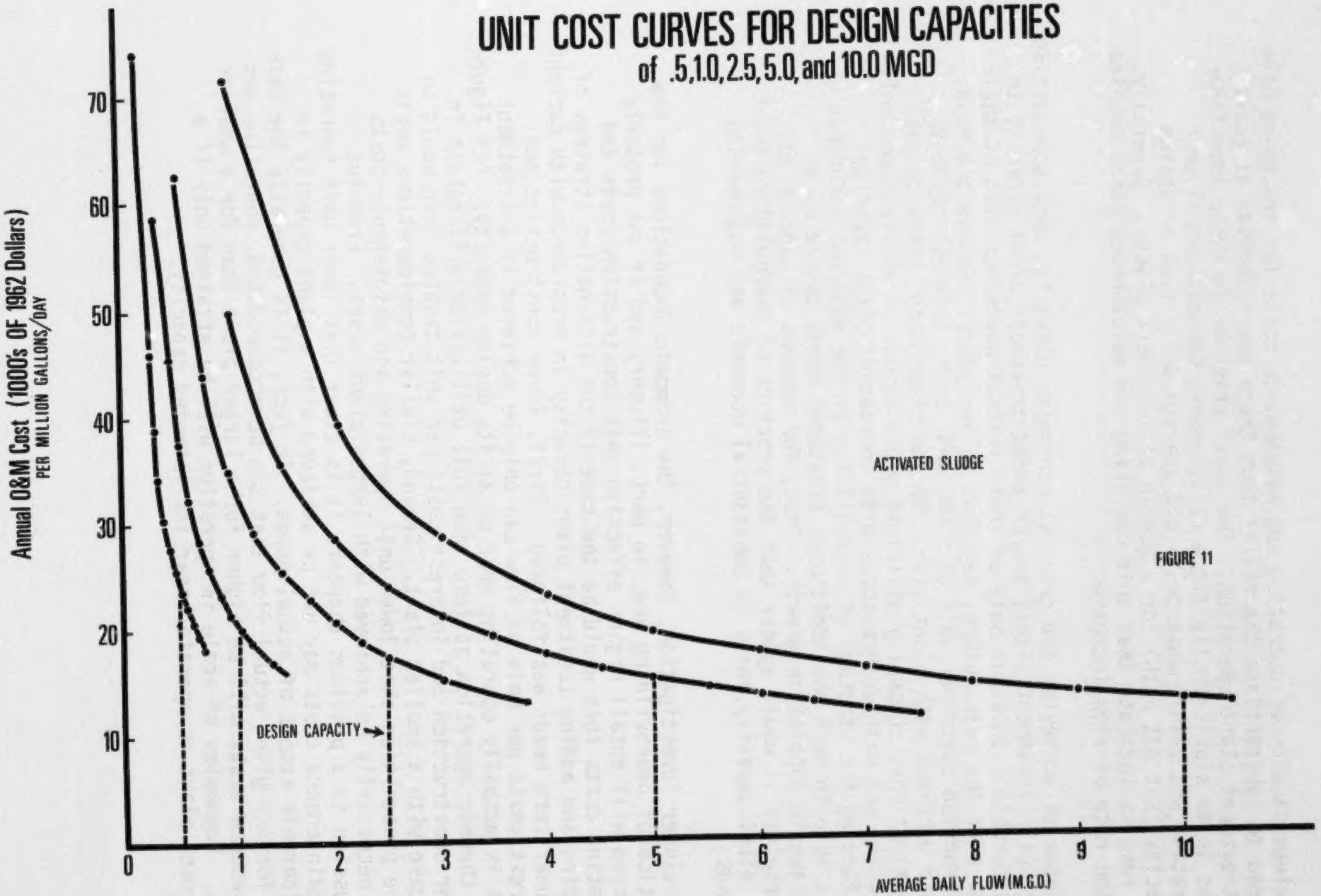

FIGURE 11

Finally, to build an overdesigned treatment plant in order to meet possible unexpected increases in demand is a one-sided strategy that ignores the full range of alternatives. The possibility that future demand might exceed forecasted demand arises because of the confidence with which the forecast is held. However, if a forecast is not held with certainty, then it is generally the case that future demand can fall short of the forecast with about the same probability as rising above the forecast. What, then, are the alternative design strategies when demand forecasts are not held with certainty? On the one hand, a plant can be built to accommodate treatment needs in excess of currently forecasted needs. However, if actual future demand is not above forecasted demand, then the community incurs higher construction, operating, and interest costs on both a total and per-unit basis than would be the case if a smaller plant had been built. On the other hand, a plant can be built to meet current and short-range needs, say five to ten years, and the community can build increments to treatment plant capacity to meet additional needs as they occur. A potential loss is associated with this latter strategy, though; namely, if future demand is higher than forecasted, then the economies of scale associated with a larger plant have been foregone. Under uncertainty, which of these two general strategies should be pursued? A recent study has indicated that the strategy of overbuilding treatment plant capacity in order to meet unexpected increases in future treatment needs is generally imprudent. */ The rationale behind this finding is that, generally, the expected loss from building incrementally to meet short-term needs stemming from the potentially foregone economies of scale is less than the expected loss from overbuilding stemming from the potential higher costs of construction and operation.

Thus, economies of scale and safety margins are not, in and of themselves, sufficient economic justifications for overbuilding treatment plant capacity. Only if a community is expected to operate its treatment facility near full capacity within the near future, say five to seven years, will the potential cost savings be realized. In general, a strategy of building capacity to meet current and near-term needs will yield lower costs of construction and operation than the strategy of overbuilding.

Peak Loading

A community's hydraulic characteristics must be incorporated into the design characteristics of its treatment plant in order to attain

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*/ *Ibid*. pp. 1195-1206

target degrees of treatment. The expected peak load is one of the most important characteristics that must be considered in meeting design efficiencies of a plant on a continual basis. Peak loads can be met by a combination of three basic methods: varying detention times and recirculation rates, use of flow equalization devices or tanks to smooth the flow of influent and permit processing at non-peak periods, and building sufficient operating capacity to handle peak loads as they occur.

If it is the case that anticipated peak loads are met primarily by building sufficient capacity to meet them as they occur, then this practice will contribute to the prevalence of stated excess capacity. To illustrate, suppose that two communities plan to treat the same average daily flow, say one million gallons per day, but that the first community has an average peak at a daily rate of 1.2 million gallons and the second has a peak of 2.0 million gallons. If these peaks are met solely by building capacity to handle them, then the first community will build a plant with a smaller design capacity than will the second community. Consequently, the first community's plant will have a higher calculated utilization rate (actual flow/design flow) than the second community's plant. From this example it can be seen that if it is common design practice to build enough treatment plant capacity to meet peak loads as they occur, then it might be expected that observed lower rates of utilization are associated with higher peak loads.

The validity of this partial explanation for the prevalence of excess capacity can be statistically tested by computing the correlation between the rate of capacity utilization and a measure of peak loading. A negative correlation between these two variables is expected if the practice of using excess capacity in order to meet peak loads is prevalent. The rate of utilization is measured by the ratio of actual average daily flow to design capacity and peak loading is measured by the ratio of peak load to average daily flow.

The statistical results are reported in Table 31. As can be seen by inspection of the first row of this table, the correlation between peak loading and utilization rates is negative but low (a value of -1.0 denotes perfect negative correlation, 0 is perfect non-correlation, and 1.0 is perfect positive correlation). Each correlation is, however, significantly negative (i.e., significantly below zero) by the usual tests of statistical significance. In the second row of the table the

TABLE 31

Treatment Type	Primary	Activated Sludge	High-Rate Trickling Filter	Standard-Rate Trickling Filter	Stabilization Ponds
Correlation Coefficient	-.221	-.292	-.224	-.290	-.188
Percent of Variation Explained	4.9	8.6	5.0	8.4	3.5
Average Utilization Rate	.62	.67	.64	.66	.67
Average of Peak Load/Average Daily Flow	3.55	2.75	2.85	4.18	2.25
Number of Plants in Sample	158	77	159	77	41

Table 31. Statistical Relationships between capacity utilization and the ratio of peak load to average daily flow.

percentages of variation between plants in capacity utilization attributable to variation between plants in peak loadings are reported. The percentage of explained variation ranges from a low of 3.5 percent for stabilization ponds to a maximum of only 8.6 percent for the activated sludge process. In other words, less than nine percent of variation in utilization rate can be accounted for by peak loading, and so justifiable on an engineering basis. The remaining 90-odd percent is attributable to factors other than peak loading.

APPENDIX A

THE NATIONAL INDUSTRIAL CONFERENCE BOARD INCORPORATED
845 THIRD AVENUE, NEW YORK, N. Y. 10022

Budget Bureau No. 42–S69006
Approval Expires Dec. 31, 1970

SURVEY QUESTIONNAIRE

STUDY OF WATER POLLUTION ABATEMENT COSTS

General Directions

A separate report should be prepared for each plant. It is necessary to know these data for each plant so as to relate the production and financial data to the wastewater abatement cost data when making cost burden and incentive analyses.

A plant is defined as the total facilities and operations at one location. Whether a few or many products are made at this location, it still should be considered one plant. This excludes facilities restricted entirely to such operations as warehousing and storage, research and development, and sales offices.

In the preparation of this survey questionnaire, care was taken to request information, wherever possible, in terms identical to those utilized in various reports to the Bureau of the Census. This was done to provide a recognized standard for some of the information requested and to permit the respondent to provide information similar to that which has been compiled for other reports.

Please report for *calendar year 1969* unless otherwise specified. If this is not possible, specify the reporting period for which data are provided. ______________________________

Please return the completed form to *Leonard Lund, National Industrial Conference Board, 845 Third Avenue, New York, New York 10022.* Do not indicate your name or company on this form. The Code Number on this page identifies you to The Conference Board. No personal or corporate identification will appear in any report based on this survey without your explicit authorization.

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ITEM 1. PRODUCT INFORMATION

(a) Principal product(s) of this plant

(Describe by using categories defined in the Standard Industrial Classification Manual, e.g., "Chemicals and Allied Products," "Industrial Gases," "Food and Kindred Products, Fluid Milk," "Transportation Equipment, Motor Vehicles," or similar descriptive phrases.)

(b) Standard Industrial Classification Code(s). (If known)

(4 digit code(s))

ITEM 2. NUMBER OF EMPLOYEES

(a) **Production Workers**—Workers (up through the working foreman level) engaged in fabricating, processing, assembling, inspecting, receiving, packing, warehousing, shipping (but not delivering), maintenance, repair, janitorial, watchman services, product development, auxiliary production for plant's own use (e.g., powerplant), recordkeeping, and other closely associated services. Exclude proprietors and partners.

Number of production employees during typical month

(b) **All Other Employees**—Nonproduction personnel, including those engaged in the following activities: supervision above working foreman level, sales (including driver salesmen), sales delivery (truck drivers and helpers), advertising, credit, collection, installation and servicing of own products, clerical and routine office functions, executive, purchasing, finance, legal, personnel (incl. cafeteria, etc.), professional and technical. Exclude proprietors and partners.

Number of all other employees during typical month

(c) Total number of employees (sum of lines a and b)

ITEM 3. PAYROLLS

Enter the total (before deductions) of wages, salaries, bonuses, commissions, and other remunerations paid in 1969 to "Production Workers," and "All Other Employees," as defined in Item 2 above.

a) Production workers' wages $

b) All other employees' salaries and wages $

c) TOTAL PAYROLL (Sum of Lines a and b) $

ITEM 4. PRODUCTION COSTS

(a) What were the costs of materials, fuels, electricity and contract work put into production in 1969?
$ ____________________

Note: The figures reported should represent the total cost of materials, supplies, semi-finished goods, fuels, etc., actually consumed or put into production as in reports to the Census Bureau.

If your records do not show the amounts actually consumed or put into production, the reported figures may be derived from purchase and other records.

(b) What were the depreciation charges in 1969? $ ____________________

ITEM 5. VALUE OF SHIPMENTS

What was the value of products shipped in 1969? $ ____________________

ITEM 6. VALUE AND AGE OF FIXED ASSETS

In order to obtain an estimate of the value and age of the plant and equipment, please answer the following:

(a) What was the gross investment in plant and equipment as of December 31, 1969? $ ____________________

(b) What was the book value (gross investment minus straight line depreciation) of plant and equipment?
$ ____________________

(c) Was the plant built within the last five years? Yes ☐ No ☐

(d) Was the capacity of this plant expanded significantly (more than 50%) within the past five years? Yes ☐ No ☐

(e) Was more than 50% of the production equipment in this plant installed or significantly modified within the past five years? Yes ☐ No ☐

ITEM 7. CAPITAL EXPENDITURES FOR ABATEMENT FACILITIES

(a) Please estimate the capital expenditures for the purpose of water pollution abatement at this plant for each year of the period 1965-1969. Report separately the amounts spent for *replacement and modernization of existing facilities* and the amounts spent for *new facilities including expansion.*

Note: Report only those expenditures made for the purpose of pollution abatement. If improvements have been made in the production process which provide an incidental benefit in the abatement of pollution *do not* include the expenditure for that improvement.

Year	Replacement and modernization of existing facilities	New facilities including expansion	Total Expenditure
1965	$__________	$__________	$__________
1966	$__________	$__________	$__________
1967	$__________	$__________	$__________
1968	$__________	$__________	$__________
1969	$__________	$__________	$__________
Total (1965-1969)	$__________	$__________	$__________

(b) For which of the following types of water pollution abatement measures were most of the capital expenditures made at this plant during 1965-1969? (If the investment falls primarily in one category, check that box; if it is divided among several, check all appropriate boxes for which expenditures were more than 20% of total.)

Manufacturing changes to reduce water pollution . . . . ☐

Wastewater treatment . . . . ☐

Water cooling (See Note below) . . . . ☐

Other (please specify) ____________________________ . . . . ☐

Note: Water cooling done primarily to reduce the quantity of intake water needed for production purposes is not considered pollution abatement. Cooling for the purpose of preventing the discharge of heated water to a river, lake, stream, or estuary, is considered pollution abatement.

(c) If this plant currently has no water pollution abatement facilities, does it plan to build any? Yes ☐ No ☐
If yes, when? Next year ☐ In five years ☐ After that ☐

ITEM 8. PLANNED CAPITAL APPROPRIATIONS FOR POLLUTION ABATEMENT FACILITIES

Please report:

(a) Capital appropriation for abatement facilities for 1970 $________________

(b) Number of years in which to be spent ________.

(c) For which type of measures: (see 7b)
- Manufacturing process changes ☐
- Wastewater treatment ☐
- Water cooling (see Note 7b) ☐
- Other (specify) ☐

____

Please report:

(d) Total future capital requirements, including 1970, to meet present water quality standards $____________________

(e) Number of years in which to be spent ________

(f) For which type of measures: (see 7b)
- Manufacturing process changes ☐
- Wastewater treatment ☐
- Water cooling (see Note 7b) ☐
- Other (specify) ☐

____

ITEM 9. WATER POLLUTION ABATEMENT MEASURES

Using the accompanying chart of abatement measures (Attachment I), please indicate the code numbers of those measures already in place in this plant, and in the order in which applied. In the event that wastewaters from more than one source within the plant are combined for treatment in a common facility (e.g., process and sanitary wastewaters) please indicate this by showing which sources are combined.

Wastewater Source	Abatement Measure Code Numbers
Manufacturing process	________________
Sanitary	________________
Cooling (see Note 7b)	________________
Other – (please specify)	
____________________	____________________
____________________	____________________

ITEM 10. VOLUME AND CHARACTERISTICS OF DISCHARGED WASTEWATERS

(a) Average daily volume of discharged wastewater by source:
(Report typical discharges in million gallons per operating day.)

Source	Discharged Directly		Discharged to Public Sewer		Other manner of disposal (specify)_____	
	Treated	Untreated	Treated	Untreated	Treated	Untreated
Manufacturing Process						
Sanitary						
Cooling (see Note 7b)						
Other (specify) ______						
Total	mgd	mgd	mgd	mgd	mgd	mgd

(b) Wastewater constituents discharged directly by source: (Report in pounds per day, pH units, degrees Fahrenheit)

Source	Biochemical Oxygen Demand (Five Day)	Chemical Oxygen Demand	Suspended Solids	pH	Temperature Rise	Other (Please specify)
Manufacturing Process						
Sanitary						
Cooling (see Note 7b)						
Other (Please specify) ______						
TOTAL						

(c) Please describe any seasonal aspects of production that may affect the quantity of wastewater discharged.

____

ITEM 11. EXPENDITURES FOR OPERATION AND MAINTENANCE OF WATER POLLUTION ABATEMENT FACILITIES

(a) Annual expenditures for operating and maintaining existing water pollution abatement facilities. 1968 $____________ 1969 $__________.

(b) Estimate of annual expenditures for operating and maintaining abatement facilities upon completion of construction noted in ITEM 8d. $__________.

(c) Estimate of number of employees engaged in operating and maintaining pollution abatement facilities in 1969.____________________
(Equivalent full-time manpower)

ITEM 12. USE OF PUBLIC SEWER SYSTEMS

(a) Is there a public sewer system available for use by this plant? Yes ☐ No ☐

(b) If yes, does this plant discharge wastewater into public sewer? Yes ☐ No ☐

If answer to (b) is Yes:

(c) What was annual payment by this plant to municipality or other authority for sewer service, excluding property tax? $________

(d) What was basis of payment? (Check all relevant boxes)

Water use	☐
Waste strength	☐
Over-strength surcharges	☐
Other (Specify)	☐

____

If answer to (b) is No:

(e) If plant does not, does this plant plan to use public sewer in the future? Yes ☐ No ☐

(f) If yes, when? Next year? ☐
In five years? ☐
Later? ☐

(g) If yes, what kind of wastewater will be discharged? Please check.

All wastewater	☐
Manufacturing process only	☐
Sanitary only	☐
Manufacturing process and sanitary	☐
Cooling (see Note 7b)	☐
Other (specify)	☐

____

ITEM 13. OTHER CONTRIBUTIONS TO FINANCING OF PUBLIC SEWER SYSTEM

(a) What payments were made to a local government unit for sewer service in the form of property taxes or assessments? $____________________

(b) What, if anything, has been contributed to the capital cost of constructing a new public wastewater treatment facility or expanding of an existing facility in cooperation with a municipality or other public authority in addition to amounts reported above? $____________________

ITEM 14. GENERAL OBSERVATIONS

We would appreciate any observations which you would care to make regarding features of the operation or location of this plant that you feel would make for special problems in wastewater treatment; and any comment you may wish to make concerning this questionnaire or the use of the data provided. If any costs have been incurred or are anticipated because of plant relocation or process change primarily influenced by water pollution abatement requirements, please describe their nature and costs in this section.

ITEM 15.

Name and title of person to be contacted in the event that additional correspondence or information may be required.

Name____

Title ____

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